Casing Failures in High Temperature Wells

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ABSTRACT

Prerequisite for utilizing the hot fluid deep in the geothermal field is a reliable well design and that casing failure will not result in abandonment of wells drilled for utilizing this fluid. Due to thermal expansion casing failed in both of the wells drilled until now in the Iceland Deep Drilling Project i.e. in IDDP-1 and IDDP-2. Similar failures of casings have also occurred in unusually hot conventional geothermal wells. The casing failures in IDDP-1 and IDDP-2 and casing failures in couple of unusually hot conventional geothermal wells will be described, the causes of these failure discussed and how this can be mitigated.

1. Introduction

Drilling for and utilizing fluid from superhot geothermal resources may be a feasible way of utilizing geothermal energy. The main opportunities are related to higher output of energy rich fluid from production wells. Therefore, fewer wells need to be drilled, footprint of the power plant will be smaller, electrical generation more effective, and opportunities may be to expand existing power plant by drilling below existing wells and increase the size of the reservoir by deepening it. The most critical component in this kind of utilization will be the wells. They must be designed to withstand the high temperature and aggressive chemistry of the fluid and challenges during drilling must be solved. There may, however, also be opportunities to sweep heat from the reservoir by injecting water into deep wells reaching below the existing production wells. The design conditions of such deep injection wells will be less stringent than design conditions for deep production wells.

The geothermal fluid in conventional hydrothermal systems is usually a boiling two-phase fluid of enthalpy below 2000 kJ/kg. Wells producing dry steam are usually fed from steam caps on top of a reservoir or decline in pressure resulting in reservoir dry-out, such as in the Geysers in

California USA. The wellhead pressure of those wells is usually not high and the temperature usually below 250 °C. Wells and wellheads are usually designed according to ASME Class 900 and in some cases Class 1500. The wellhead pressure in some wells in the geothermal power stations in Krafla (well KJ-34), Þeistareykir (well TH-04) and Hellisheidi (HE-45) is or has been up to and above 100 bar when the wells are shut in and corresponding temperature well over 300 °C. These wells are in operation, and some have been utilized for more than 20 years without problems.

IDDP-1 and IDDP-2, wells which were intended to produce superhot fluid, have both suffered failures of casings, which are related to thermal expansion, though in a different way. Examples of other casing failures of other wells are well HE-53 in Hellisheidi, Iceland and well OW-740A in Olkaria, Kenya.

2. Description of Casing Failures

Failures in IDDP wells and HE-53 in Hellisheidi and OW-740A in Olkaria are described below.

2.1 IDDP-1

IDDP-1, the first of the three IDDP wells planned, was drilled in the Krafla Geothermal Field in 2008–2009 by Landsvirkjun, the National Power Company of Iceland. The well was designed to reach supercritical conditions at 4500 m, temperatures above 374 °C and pressures above 22 MPa. Drilling progress was as planned down to around 2000 m when drilling became quite challenging, including becoming stuck at 2094 and 2095 m depth, followed by twist offs and subsequent side tracking. Finally, drilling came to an end at 2096 m depth in the third leg when cuttings of fresh glass indicated the presence of a magma body at the bottom. An as-built drawing of the well is presented in Figure 2.

Cementing the innermost casing, ø9-5/8”, was challenging and water was most likely entrapped between the ø9-5/8” production casing and ø13-3/8” anchor casing at the intersections between two cementing operations at about 610 m. This water caused a collapse of the ø9-5/8” casing already in the initial flow test as the well was successfully logged to bottom on March 15. 2010, but the logging tools stopped roughly at 620 m when logging March 24. The discharging of the well started March 22. This damage did though not prevent the well from discharging and during the flow test the flow from the well was up to 50 kg/s of fluid with enthalpy close to 3200 kJ/kg. Temperature of up to 440 °C was measured at wellhead during the flow test.

The well was discharged intermittently from March 2010 until July 2012. During this time the well was shut in several times for periods of up to 8 months. These stops were needed to modify the discharge system on top of the well. In July 2012, leakage was discovered in a ø2” nozzle in the discharge system but both the master valves failed and were stuck in their fully open position, when attempt was made to shut in the well. The operators had no alternatives but to quench the well by injecting water into it.

The well was inspected several times using a video camera after it had been quenched. The video camera was run to maximum depth of 1485 m after a rig had been installed on the well and drilled through the damage at 610 m. An overview of damages observed during this inspection is presented in the following table.

Depth [m]	*Damage*	*Comment*
296	Broken casing, pin pulled 400 mm down from box	
348	Broken casing, pin pulled 180 mm down from box	Cannot be seen in video 2012
498	Broken casing, pin pulled 300 mm from box	
611	Collapse of production casing, damages on anchor casing	Indication of leakage was observed more than a year after quenching
994	Limited collapse of casing	
1178	Broken casing about 1,6 m above a connection	
1338	Broken casing, pin pulled 500 mm down from box	

The broken casing damages can only be caused by contraction of the casing when it has been cooled. Although there may have been some fluctuation in the temperature of the casing during discharging and shut-in by far the largest temperature shock was when the well was quenched, and failures are most likely related to the quenching.

Pictures from the damage at 610 m are shown in Figure 1. Several meters of the ø9-5/8” casing had fully collapsed, and the steam had flown in the annulus between the ø9-5/8” and ø13-3/8” casings in this interval. This flow restriction was not observed when the well was discharged and as there were three casing strings in the well at this depth, this failure did not compromise the integrity of the well.

The maximum depth of the drill bit during the work over of the well was 1760 m and drilling/reaming below 1600 m was problematic. This was most likely due to damaged casing, which was not cemented below 1490 m and likely to be corroded as well.

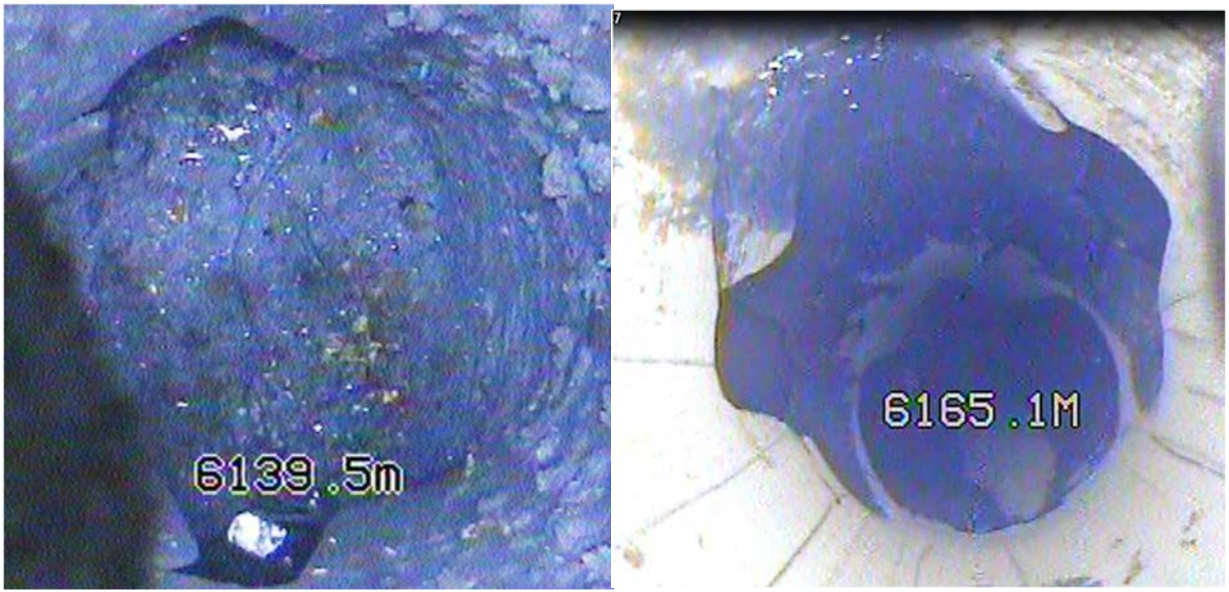


Figure 1: IDDP-1, damages at 610 m depth before and after drilling through the damage

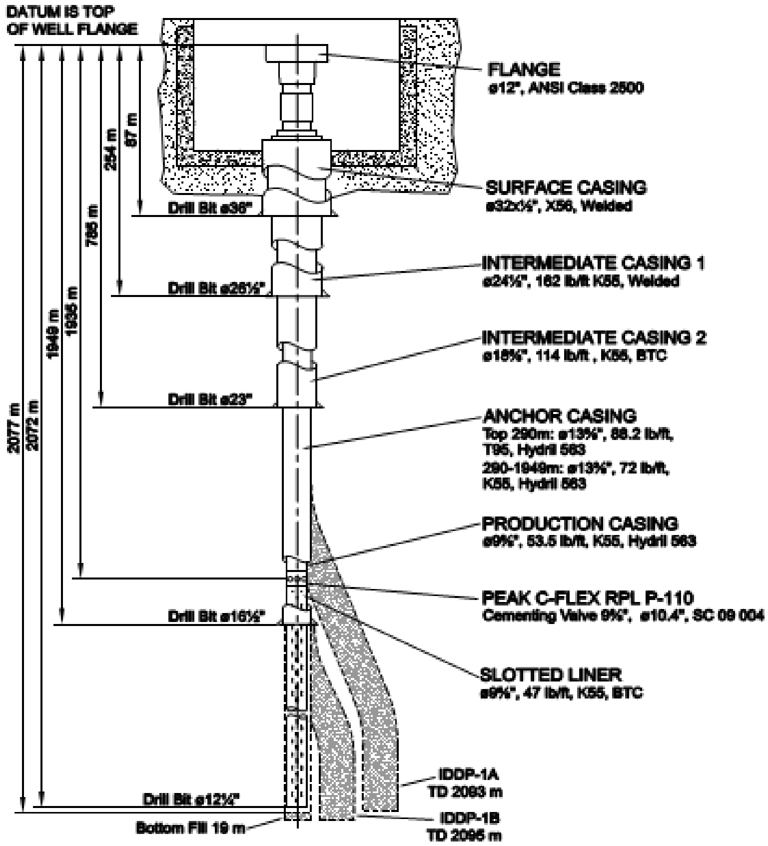


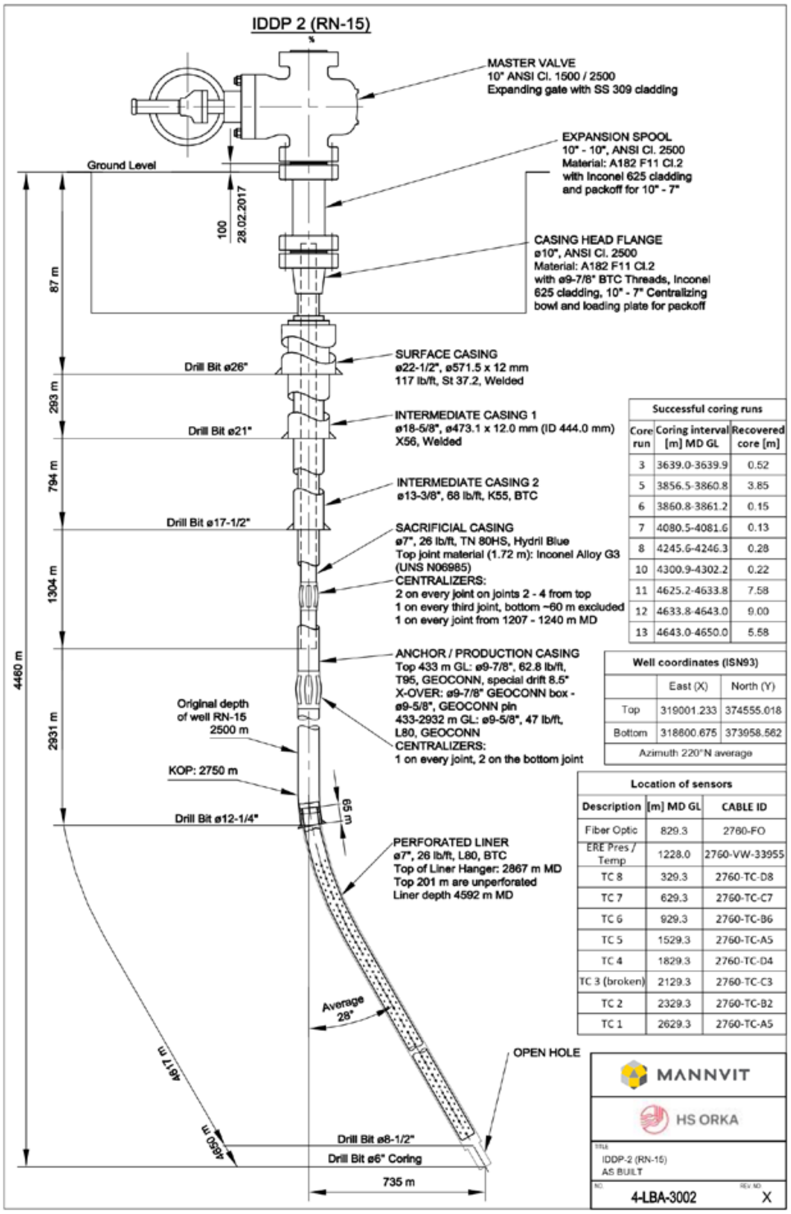
Figure 2: IDDP-1 as-built

2.2 IDDP-2

The drilling of the second IDDP well, IDDP-2, was completed in January 2017. A 2500 m deep well, RN-15, was deepened to depth of 4650 m and thus making it the deepest high-temperature well in Iceland. An as-built drawing of the well is presented in Figure 3.

A ø9-5/8” casing was run from surface, through the original production section of the well, down to 2930 m depth and cemented using reverse cementing method. Cement bond logging (CBL) and temperature logging after the casing had been cemented indicated poor or no cement at an interval of 100 m or more below 2.3 km depth. The reason for this is likely use of retarder in the cement slurry in the bottom part of the well but not in the upper part. Casing failure was later observed in this interval. At that time the casing had gone through temperature cycles, though relatively moderate and maximum temperature unlikely to have been higher than 200 °C.

During drilling supercritical conditions were measured at 4550 m depth, 426 °C at 340 bar. Cores drilled and retrieved from the bottom of the well proved as well the well had been drilled into supercritical conditions. The casing failure at 2300 m depth in IDDP-2 did not stop attempts to discharge the well. But the flow from the well has been conventional geothermal fluid, not supercritical from the bottom.



Successful coring runs

Core run	Coring interval [m] MD GL	Recovered core [m]
3	3639.0-3639.9	0.52
5	3856.5-3860.8	3.85
6	3860.8-3861.2	0.15
7	4080.5-4081.6	0.13
8	4245.6-4246.3	0.28
10	4300.9-4302.2	0.22
11	4625.2-4633.8	7.58
12	4633.8-4643.0	9.00
13	4643.0-4650.0	5.58

Well coordinates (ISN93)

	East (X)	North (Y)
Top	319001.233	374555.018
Bottom	318800.675	373958.562
Azimuth 220°N average		

Location of sensors

Description	[m] MD GL	CABLE ID
Fiber Optic	829.3	2760-FO
ERE Pres / Temp	1228.0	2760-VW-33955
TC 8	329.3	2760-TC-D8
TC 7	629.3	2760-TC-C7
TC 6	929.3	2760-TC-B6
TC 5	1529.3	2760-TC-A5
TC 4	1829.3	2760-TC-D4
TC 3 (broken)	2129.3	2760-TC-C3
TC 2	2329.3	2760-TC-B2
TC 1	2629.3	2760-TC-A5

Figure 3: IDDP-2, as built

2.2 Conventional Wells

Well HE-53 on Hellisheidi, Iceland was drilled in the spring of 2009. Anchor casing depth is about 300 m and production casing 960 m. The well was directionally drilled, and true vertical depth of the well is 2250 m. The production section was drilled using ø8-1/2” drill bit.

The well was discharging from end of July and into October 2009. It was quite powerful and produced 50 – 60 kg/s of about 2500 kJ/kg fluid. After shut-in following the flow testing, the wellhead pressure rose to 104 bar. Efforts were made to lower the wellhead pressure as there were no plans to utilize the well at the time. Similar methods were used as has successfully been used for other wells, i.e. bleeding of gas and pumping of water into the well. This was not successful and in the end powerful pumps were used in an attempt to quench the well. This was not successful either and temperature logging in a well close to HE-53 clearly showed steam flowing from it at about 300 m depth, i.e. just below the anchor casing.

The leakage was developing into a serious blowout and decision was made to pump cement down the hole. This was successful and later, after the top part of the cement had been drilled, the casing was inspected using a video camera. The casing was broken in two places, at 130 m depth where the pin broke at a lower end of a coupling creating a gap of 300 – 400 mm and 303 m depth where the pin broke at the upper end of coupling creating a gap of 500 – 600 mm. Pictures of the damage at 303 m depth are shown in Figure 4.

A ø7” liner was run and cemented in the well covering the damaged parts. Figure 5 shows the well after repair. The well has been producing for the past years though at lower output than originally measured.

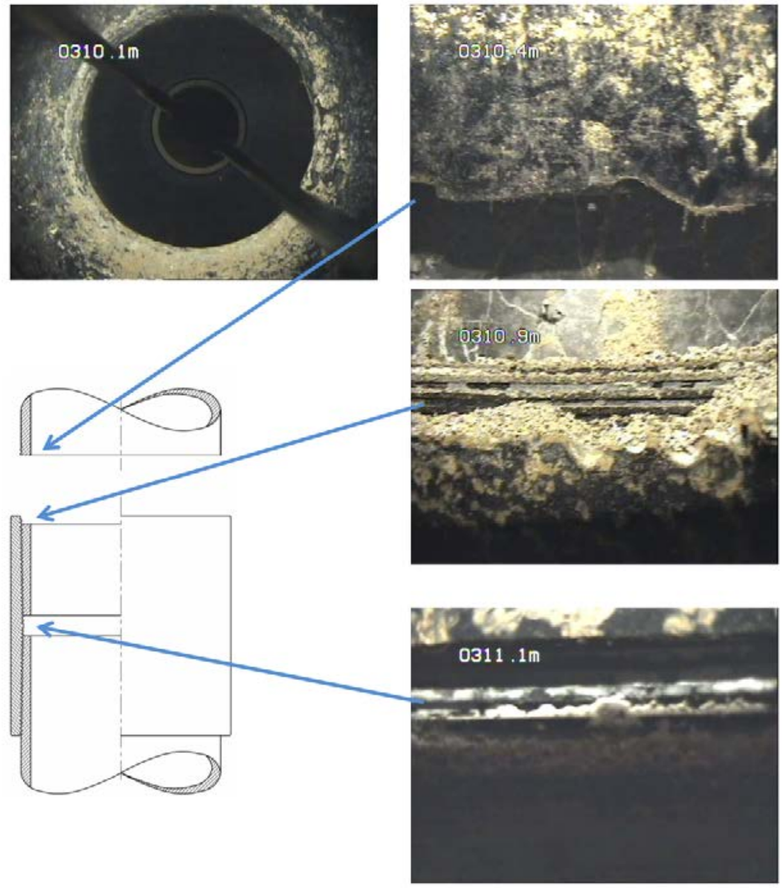


Figure 4: HE-53, damages of the ø9-5/8” production casing at 303 m depth

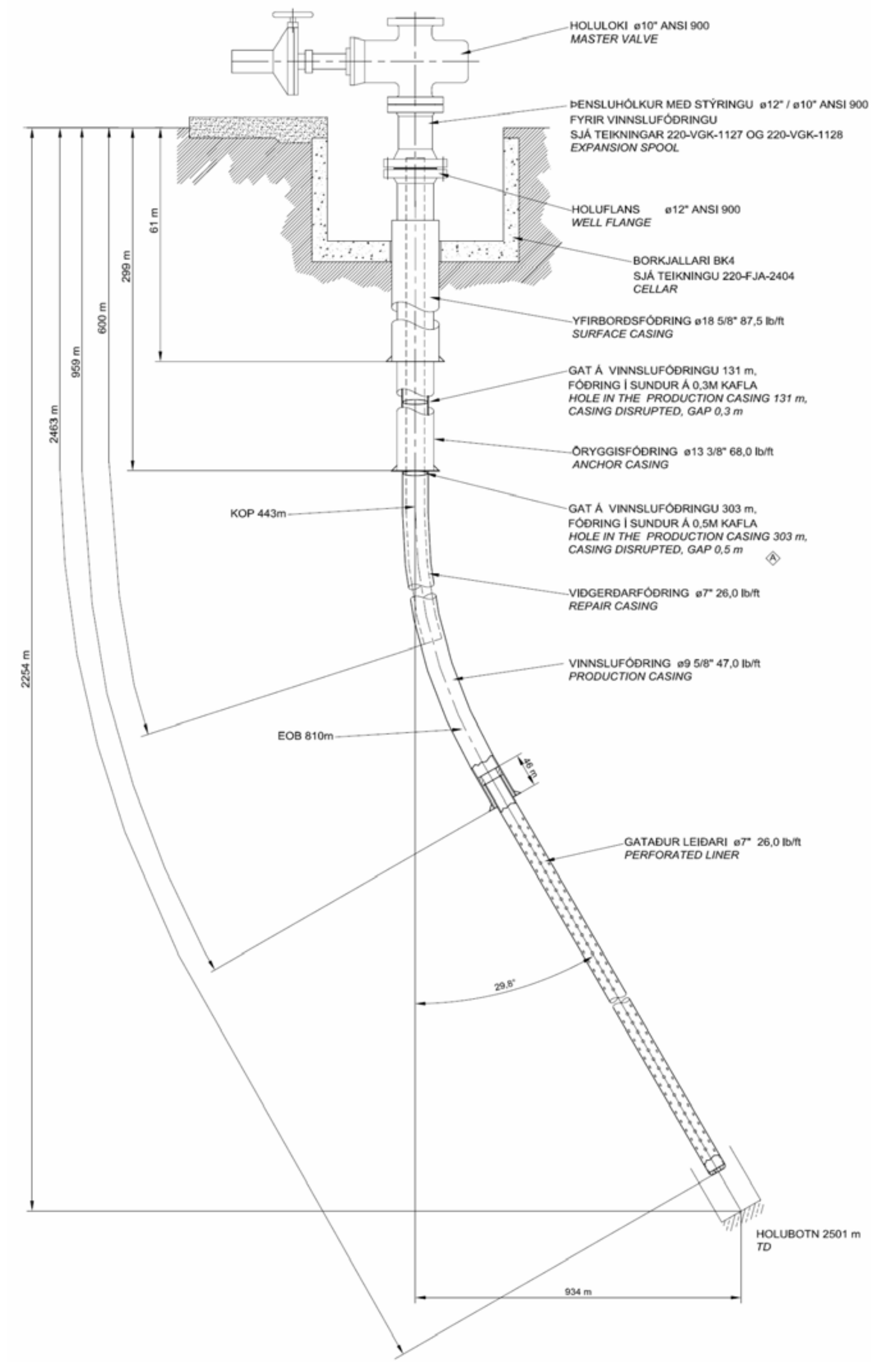


Figure 5: HE-53 after repair

Well OW-740A in Olkaria, Kenya, was drilled in 2018 to a total depth of about 3000 m. The production casing is about 1000 m deep and the anchor casing about 300 m. The production section of the well was drilled using ø8-1/2” drill bit.

The well was flow tested in the summer of 2018, few months after the drilling was completed, and was discharging for about two months. The well turned out to be good producer, the total flow from it was over 16 kg/s and the enthalpy of the fluid was over 2500 kJ/kg. The wellhead pressure when shut-in was 106 bar. In the summer of 2019, steam leakage was observed between surface and anchor casing and from a fracture in the cellar. The well was quenched to stop the leakage and investigate the casing. A multi-finger caliper logging indicated the casing was apart in three locations, at about 180 m, 190 m and 310 m. The upper two damages are inside the anchor casing but the lowest one a few meters below the anchor casing shoe.

The well was shut-in after the quenching, but the wellhead pressure rose, and steam leakage started again and worse than before. The pressure was relieved by discharging the well and this has been sufficient to stop the steam leakage.

2. Discussion

The cause of the casing failure in IDDP-2 is different from other failures discussed and described above. The most likely reason is a long, probably more than 100 m, uncemented casing below 2300 m depth and even though the temperature changes were relatively moderate, it was enough to cause the damage. The root cause was the cementing.

A fault in the cementing in IDDP-1 caused collapse and other casing damages at 610 m depth. These damages were observed during the heating up of the well, when a logging tool could no longer be run below this depth. After the quenching these damages could be inspected and the innermost ø9-5/8” casing turned out to be badly damaged as can be seen in Figure 2. These damages did though not give problems during the discharging of the well. Neither was the well integrity compromised as there were two casing strings outside the ø9-5/8” casing at this depth, i.e. ø13-3/8” and ø18-5/8”.

No defect in the cement were known in the five places where the production casing in IDDP-1 broke and those damages can therefore not be directly related to poor cement. One may though argue that a perfect cementing should keep the casing in place even in extreme conditions like during quenching.

The history of HE-53 in Hellisheidi, Iceland, and OW-740A in Olkaria, Kenya, are similar. In both cases leakages were discovered in the production casings just below the anchor casing shoe after the wells were shut-in following initial discharge tests. It is difficult to confirm the reason for the damages, but poor cementing is likely to play a role. The anchor casing shoe may also add to the load on the production casing. OW-740A was successfully quenched using water but cement was needed to kill HE-53. Inspection of the wells, after they had been quenched, revealed the production casings had in both wells broken at 130 – 190 m depth. Given the operational history of the wells, those damages are most likely caused by the quenching or an attempt to quench.

As listed in the Introduction, wells have successfully been operated at temperature over 300 °C. Those wells have been shut-in but never quenched using cold water. Given the track record described above, it must be concluded that quenching using cold water of wells hotter than 300 °C and which are constructed with conventional casing material and conventional connection, is highly likely to cause damage of the casing.

Thermal expansion is a displacement load rather than a force. The stress in a fully constrained casing will be above the yield point of most casing material if temperature of the well is more than 230 °C. The strain is, however, less than 0,5% while the casing material will not break until the strain is 20 – 30% when tested at room temperature and normal atmosphere. Structural analysis of casings in hot wells should therefore be aimed at the strain rather than the stress in the casings.

REFERENCES

Friðleifsson, G.Ó., W.A. Elders, R.A. Zierenberg, A.P.G Fowler, T.B. Weisenberg, K.G. Mesfin, Ó. Sigurðsson, S. Nielsson, G.M. Einarsson, F. Óskarsson, E.G. Guðnason, H. Tulinius, K. Hokstad, G. Benoit, G. Nono, D. Loggia, F. Parat, S.B Cichy, D. Escobedo and D. Mainprice, “The Iceland Deep Drilling Project at Reykjanes: Drilling into the root zone of black smoker analog”. *Journ. Volc. and Geoth. Research* (2018) (https://doi.org/10.1016/j.volgerores.2018. 08.013) (2018)

Friðleifsson, G.Ó., Albertsson, A., Stefansson, A., Thorolfsson, Mesfin, G.K., Matthiasdottir, K.V., Sigurdsson, K., Sigurðsson, Ó., Gislason, Th., Elders, W.A., Zierenberg, R.A., Bali, E., Gudnson, E.A., Óskarsson, F., Weisenberg, T.B. “The IDDP-2 DEEPEGS Demonstrator at Reykjanes – Overview” *Proceedings: World Geothermal Congress 2020,* Reykjavik, Iceland April 26 – May 2, 2020.

Hólmgeirsson, S., Guðmundsson, Á., Pálsson, B., Bóasson, H.Á., Ingason, K., Thórhallsson, S., “Drilling Operations of the First Iceland Deep Drilling Well (IDDP)”. *Proceedings: The World Geothermal Congress*, Bali, Indonesia, April 25–29, 2010, paper 2129 (2010).

Ingason, K., Kristjánsson, V., Einarsson, K. “Design and development of the discharge system of IDDP-1”. Geothermics 49, 58–65 (2014).

Ingason K., Árnason A. B., Bóasson H.Á, Sverrisson H., Sigurjónsson, K.Ö, Gíslason Þ. „IDDP-2, Well design“. *Proceedings: World Geothermal Congress 2015*, Melbourne, Australia 19-25 April 2015.

Ingason, K., Sigurdsson, TH. „Design of Superhot Wells“. *Proceedings: World Geothermal Congress 2020,* Reykjavik, Iceland April 26 – May 2, 2020.

Mannvit, “IDDP-1 Inspection and Results”. *A report made for Landsvirkjun*, March 2017

Nzioka, N. K. “Casing Failure Analysis and Proposed Repair for Well OW-740A in Olarkia Geothermal Field”. *Geothermal training in Iceland 2021*.

Pálsson, B., Hólmgeirsson, S., Gudmundsson, Á., Bóasson,H.Á., Ingason, K., Sverrisson, H., Þórhallsson, S., Drilling of the well IDDP-1. Geothermics 49, 23–30 (2014).

Stefansson, A., Fridleifsson, G.O., Sigurdsson, O., Gislason, Th. „IDDP-2, DEEPEGS Drilling Experience and Lessons Learned“. *Proceedings: World Geothermal Congress 2020,* Reykjavik, Iceland April 26 – May 2, 2020.