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Do We Need a New Standard for Geothermal Downhole Tools?

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ABSTRACT

Energy has become a basic necessity for humans and its demand is increasing with each passing day. In the coming future, it is believed that renewable energy will play an important role to fulfil the desired energy requirement. While geothermal energy is considered vital in the context of renewable energy as it is the only energy source that is not affected by metrological changes. In many cases, geothermal energy extraction from the subsurface requires stimulation operations such as hydraulic fracturing. In that respect, packers play an important role as they provide zonal isolation, sustain differential pressure, and bear the axial load.

However, due to the HPHT condition and corrosive fluid presence, the conventional packer used in the oil and gas industry cannot be used in geothermal wells. The testing standard that is followed for packers grading at present might not be applicable for geothermal applications. As to those standards, V0 is considered the gas-tight seal packer with the highest rating. However, in the V0 test nitrogen gas is used while in the geothermal reservoirs the presence of gases is almost very rare.

Therefore, there is a need to develop new testing standards that is particular for geothermal condition. Until new standards are devised, packers applicable for HPHT or ultra HPHT can be used in geothermal applications. This paper gives an overview of the problem faced by the packer in the HPHT conditions, their design solutions, and the current testing standard of packers

1. INTRODUCTION

The world's population is continuously on the rise and it is expected that by 2035 the earth's population will be 8.8 billion and the energy demand will be increased by 30% (Dudley 2017). While according to Energy Information Administration (EIA) (2016) by 2040 the population increase would be about 40%. Therefore, to meet the demand for energy with the growing population the contribution should be made by both conventional (fossil fuel) and renewable energy. It is reported that by 2040, renewable energy will be more at the forefront and its energy production will be four times as of today (Dudley 2017).

At present, about 71% of renewable energy is produced through hydropower, whereas the contribution of geothermal is below 1% (WEC 2016). Nonetheless, geothermal energy presents many benefits that will make it more adaptable in the coming future. Some of those advantages are that they are available at a certain depth in many countries, can be applied in a wide range of applications, consistency, large amount of untapped resources, and are not affected by any metrological changes (Sui, et al. 2019, Budisulistyo and Krumdieck 2015, Lund 1999).

2. GEOTHERMAL SOURCE TEMPERATURE

The heat produced from the geothermal well in the subsurface either comes from the magmatic sources or from the decay of radioactive elements like 238U, 232Th, and 40K (Karakuş 2015, Bragin, et al. 2021). The heat energy can also be produced from the friction and shearing that exist in the lithosphere section.

In order to make the geothermal project viable, heat extracted from the subsurface should be used for multiple applications. Table 1 shows the different temperatures of geothermal sources and their applications

Table 1: Geothermal temperature ranges and their applications (Abid, et al. 2022)

Range	Temperature	Dominated Fluid	Application
High temperature	Above 150°C	Vapor and liquid	Fuel and power generation
Medium temperature	Around 95°C	Mostly liquid	Electricity production by utilizing binary plant
	From 90°C to 150°C		Drying of timber, refrigeration, cooling, or heating of buildings
Low Temperature	From 90°C to 30°C	Liquid	Aquaculture, processing of food, and heating of the greenhouse
	Below 30°C		Warming of soil

3. GEOTHERMAL SYSTEMS

There are different geothermal systems present such as hydrothermal systems, geopressurized systems, magmatic systems, and hot dry systems. However, at present "Enhanced Geothermal System" has taken the central stage as this system lies in between the HDR and hydrothermal systems and requires a stimulation job to improve the transfer properties of the reservoir. The temperature of the EGS ranges up to 300°C (572°F) and it is reported that by 2050 the power generation from this system would be around 70 GWe (Allahvirdizadeh 2020, Walters, et al. 2012).

4. DISTRIBUTION AND USAGE OF GEOTHERMAL RESOURCES IN THE US

The United States has been using geothermal resources for power generation. It was reported in 2020 that about 17 billion kWh of electricity was produced by the geothermal source which covers almost 0.4% of the total power utilized by the country (US Energy Information Administartion 2020). Table 2 shows the electricity produced from the geothermal resources by different states, while Figure 1 shows the distribution of geothermal resources across the US. Moreover, it is expected that by 2030 to 2050 the energy generation from geothermal resources in the US will exceed 60 GW (Welltec, Well Sustained 2022).

Table 2: Power generation of electricity from geothermal by different US states (US Energy Information Administartion 2020)

USA States	Share contributed by the state with respect to the U.S. geothermal electricity generation	Share of the electricity generated for the given state
California	70.5%	6.1%
Nevada	24.5%	10.2%
Utah	2.1%	1.0%
Hawaii	1.2%	2.2%
Oregon	0.9%	0.2%
Idaho	0.5%	0.5%
New Mexico	0.3%	0.2%

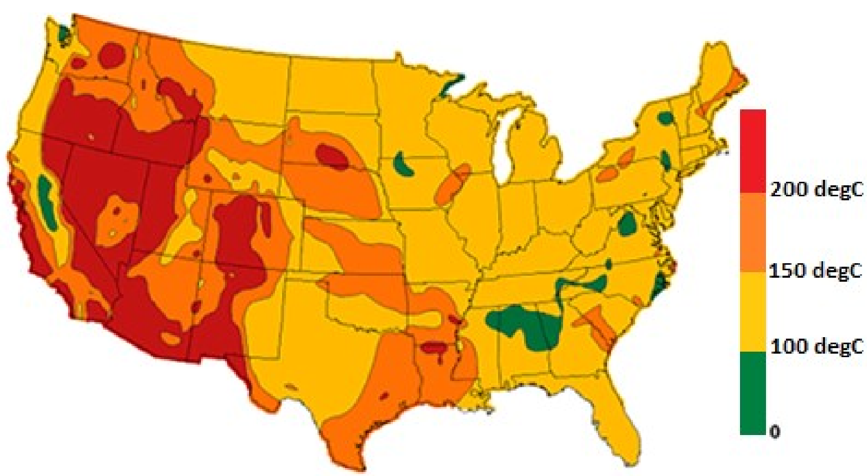

Figure 1: Geothermal resources distribution in the US (US Energy Information Administartion 2020)

5. CHALLENGES OF ISOLATION TOOLS

Potential for energy generation from geothermal resources is huge in the USA. However, improving the permeability of the reservoir in the EGS stimulation has to be done. In that respect, zonal isolation tools play an important role that maintaining the integrity of the well. Those tools have to endure high temperatures from the geothermal reservoir and high differential pressure that will be created during the fracturing of the formation. Hence, the packers that are used in conventional oil and gas well cannot be used. Therefore, specific geothermal packers that has the ability to resist such harsh environments should be used. Unfortunately, there are a limited number of packers that is specific to geothermal operations. Till then the packers that are used for HPHT or ultra-HPHT conditions can be used. However, the testing standard used for such packers also follows the conventional testing packer standard which is outlined in API Specification 11D1 and ISO 14310:2001(E) (ISO 2018, API 2002). However, these standard does not cater to the requirement of the geothermal conditions, which will be discussed in this paper. Moreover, a review of the HPHT packers by different authors will be discussed in which temperature cycle testing will be discussed.

6. STANDARDS USED FOR PACKER CLASSIFICATION

The lab standard that is used for packer standardization and classification was set by International Organization for Standardization (ISO) and American Petroleum Institute (API) and is outlined in API Specification 11D1 and ISO 14310:2001(E) (ISO 2018, API 2002). There are 6 different grades which are denoted from V1 to V6. The packer that qualifies under the V1 grade is considered the highest-rated packer and the V6 grade represents the lowest-rated packers. There is one more grade donated by V0 that is done for special purposes. The detail of these grades are as follows

V6. In this grade, the testing parameters are defined by the manufacturers. It does not follow any testing criteria of V1 to V5. Therefore, it is taken as the lowest grade

V5. The testing fluid in this grade is liquid and the packer is set under the highest temperature and maximum internal diameter for which the respected packer is rated. Whereas for the pressure testing, maximum differential pressure is given across the packer for 15 minutes and two pressure reversal is also applied. As for the retrievable packer, it is important that the packer is retrieved after the testing.

V4. In V4 testing all the parameter of V5 is used. The only addition is that during the differential pressure testing, the axial and tensile load is applied on the packer. After the testing, packer performance envelope is made.

V3. In this testing standard, all the parameters of V5 and V4 are followed. The additional temperature cycle is applied in which the packer is exposed to minimum and maximum temperatures. The test starts with the pressure and loads applied at the highest temperature in which the packer is rated. After successfully clearing that test, the temperature is reduced to a minimum temperature and, pressure and loads are applied again. Once the test is cleared at a low temperature the temperature is raised again to the highest-rated temperature.

V2. The test parameter in this grade is the same as that of the V4 with the difference being that the working fluid is gas i.e., air or nitrogen. For the packer to pass this test, a leak rate should be less than 20 cm3.

V1. The parameter of this test is the same as that of V3 but the testing fluid in this grade is gas. The allowable leakage rate should be less than 20 cm3.

V0. This is the special grade test in which the testing parameters are the same as that of V3 apart from the testing fluid, which is gas in this case. In this test, no gas leakage is allowed. Therefore, the seal of the packer should be gas-tight.

It must be noted that if any packer qualifies for the upper grade, it makes them eligible for lower grades as well. It means that if the packer qualifies for a V3 grade, it can be also used in the situation where V4, V5, and V6 grades are needed but cannot be used where V2, V1, or V0 grades are required. The summary of packer testing grades is shown in Table 3.

Table 3: Packer grades testing summary (Abid, et al. 2022)

Grade	Liquid	Gas	Pressure	Loading (Axial and tensile)	Temperature Cycle	Gas tight
V6*						
V5	✓		✓			
V4	✓		✓	✓		
V3	✓		✓	✓	✓	
V2		✓	✓	✓		
V1		✓	✓	✓	✓	
V0		✓	✓	✓	✓	✓

**V6 grade parameter is defined by the customer or manufacturer. It is the lowest grade among all*

7. HPHT PACKER TESTING REVIEW

A permanent packer was designed by Robb and Valentine (2010) which was for the 9.625in worn-out casing. As before, the conventional packers installed in a worn-out casing in HPHT condition had failed to provide efficient zonal isolation. The new packer was tested in three stages. In the first stage, the test was conducted at the temperature of 180°F with a flow rate of 3 barrels per minute to make sure that the elements of the packer i.e. tetrafluoroethylene (TFE) and AFLAS were not damaged. In the second stage application test was conducted to simulate the filed condition and the test continued until failure took place. The packer was set hydraulically by applying a pressure of 6,800 psi. For the application of tensile and axial load, hydraulic jack was used. The temperature fluctuated from 343°F to 423°F. Table 4 shows the testing condition of the application test. The test took place for over 2 hours. For the last stage of the test, the V0 test was conducted at a temperature of 450°F(232°C), having differential pressure of 15,000psi and tension and compression load of 400,000lbs. The load points of the modified V0 test are shown in Table 5.

Table 4: Application test conditions (Robb and Valentine 2010)

Step	Time (hr)	Inside Tubing (psi)	Above Packer (psi)	Below Packer (psi)	Outside 9-7/8 (psi)	Temp (°F)	Axial Force below Packer (lbf)
Initial Conditions	2	6,800	6,800	6,800	9,000	343	0
Set Packer 6,500 psi	0.25	13,300	6,800	6,800	9,000	343	0
Set Packer 6,500 psi	2	13,300	6,800	6,800	9,000	343	7,300
Annulus Test 5,000 psi	2	6,800	11,800	6,800	9,000	343	−55,000
Tubing Test 9,400 psi Annulus Test 500 psi	2	16,200	7,200	16,200	9,000	343	70,000
Tubing Test 10,900 psi, Annulus Test 13,300 psi	2	17,700	20,100	17,700	9,000	343	−70,000
Tubing Test 9,400 psi	2	16,200	6,800	16,200	9,000	343	80,000
Flowing (Annulus Pressure 1,600 psi)	48	5,500	8,400	5,500	9,000	423	−165,000
Hot Shut-in (Annulus Pressure 1,600 psi)	24	16,000	8,400	16,000	9,000	423	-80,000
Flowing (Annulus Pressure 1,600 psi)	48	5,500	8,400	5,500	9,000	423	−165,000
Cold Shut-in (Annulus Pressure 500 psi)	72	16,000	7,700	16,000	9,000	343	85,000

Table 5: Modified V0 loading test condition (Robb and Valentine 2010)

Step	Time (hr)	Inside Tubing (psi)	Above Packer (psi)	Below Packer (psi)	Outside 9-7/8 (psi)	Temp (F)	Axial Force below Packer (lbf)
1	2	15,000	0	15,000	9,000	450	200,000
2	2	15,000	0	15,000	9,000	450	−364,000
3	2	6,350	0	6,350	9,000	450	−400,000
4	2	0	10,630	0	9,000	450	−400,000
5	2	0	15,000	0	9,000	450	−250,000
6	2	0	15,000	0	9,000	450	250,000
7	2	0	12,500	0	9,000	450	400,000
8	2	10,000	0	10,000	9,000	450	400,000
9	2	15,000	0	15,000	9,000	450	200,000
10	2	15,000	0	15,000	9,000	212	200,000
11	2	15,000	0	15,000	9,000	450	200,000

Doane et al. (2012) came up with the HPHT packer in which they combined the design of ZXP and Premier seal system. The sealing system of the packer was taken from ZXP and was combined with the backup ring profile of the Premier seal system. The packer was tested at the temperature cycle of 500°F (260°C) to 250°F (121°C) having a pressure difference of 25,000 psi with 490,000 lbs and 240,000 lbs of compression and tension respectively. They came up with this idea because, in the HPHT condition, the rubber element in conventional packers becomes soft and extrudes over the backup ring, which in turn hinders the contact between the casing ID and the backup ring. The new packer design passed the test without any failure in the element or seal insert. The testing condition of this packer is given in Table 6.

Table 6: Experimental testing condition (Doane, et al. 2012)

Step	Below Packer (psi)	Above packer (psi)	Temp (°F)	Compression (lbs)	Tension (lbs)
1	25,000		500	240,000	
2	0	0	500		425,000
3		25,000	500		490,000
4		25,000	500		240,000
5	0	0	500	425,000	
*Cooling for one hour	25,000		250		
6 (the load and pressure were held for one hour)	25,000		500	365,000	

** The temperature cycle was applied in which the temperature was reduced to 250°F and a pressure of 25,000 psi was applied from the bottom and was kept at this condition for one hour after which it was reheated to 500°F.*

Doane, et al. (2013) designed a permanent production packer for as rolled casing that can be used in HPHT conditions. The packer was tested in the pressure range of 20,000psi and 17,000psi at the temperature cycle of 470°F (243°C) and going down to 300°F (149°C) and then heating back to 470°F (243°C). The packer was designed for 6.625in casing having a nominal weight of 58.8 to 60.8 lb/ft. The seal carrier was made up of Nickle Alloy C-276 while the sealing element was composed of Perfluoroelastomer (FFKM). The compression of 300,000 lbs was applied during the test. Table 7 shows the experimental condition of the test. After the validation test, it was found that both the seal insert, and element remain intact and were not damaged.

Table 7: Experimental steps for packer testing (Doane 2013)

Step	Below Packer (psi)	Above packer (psi)	Temp (°F)	Compression (lbs)	Tension (lbs)
1	20,000		470		150,000
2			470		300,000
3		17,000	470		175,000
4		17,000	470	300,000	
*Temperature cycle (470°F-300°F-470°F)			300		
5	20,000		470	300,000	

** The temperature cycle was applied at step four in which the temperature was reduced from 470°F to 300°F and then was heated back to 470°F*

Taylor, et al. 2014 extended the work of Doane, et al. (2013) and validated the packer with grade V0 testing to assure that the packer is workable in the worst-case scenario. The testing procedure is shown in table 8. After the V0 test, the packer was exposed to a 5-temperature cycle at the request of the specific operator as they were interested to deploy the packer for stimulation purposes. The temperature fluctuated from 300°F-400°F-200°F-150°F-90°F and back to 400°F. The loading procedure of this test is shown in Table 9

Table 8: Qualification load cases (Taylor, et al. 2014)

Step	Below Packer (psi)	Above packer (psi)	Temp (°F)	Compression (lbs)	Tension (lbs)
1	20,000		470°F		150,000
1	20,000		300°F		150,000
1	20,000		470°F		150,000
2	0	0	470°F		300,000
3		17,000	470°F		175,000
4		17,000	470°F	175,000	
5		5,000	470°F	300,000	
6	20,000		470°F	300,000	

Table 9: Special qualification load cases made on the operator specification (Taylor, et al. 2014)

Step	Below Packer (psi)	Above packer (psi)	Temp (°F)	Compression (lbs)	Tension (lbs)
Setting			300		
Back-side pressure held		17,000	300		47,000
1	20,000		400		150,000
1	20,000		200		150,000
1	20,000		150		150,000
1	20,000		90		150,000
1	20,000		400		150,000
2	0	0	400		300,000
3		17,000	400		175,000
4		17,000	400	175,000	
5		5,000	400	300,000	
6	20,000		400	300,000	

Mills, et al. 2016 developed a short radius packer for the open hole completion in which they used a nested backup ring that was able to extend to about 288% more than the conventional short radius packers. It was found that the stress level in the new packer even after the huge expansion was the same as that of the conventional packer. Polymeric material was used as an element in the packer. The packer was tested against the pressure of 5,000psi in gauge and 5,000psi out of gauge (extreme expansion) of the well at the temperature of 350°F (177°C) for both conditions. For the extreme expansion packer, 4 temperature cycle was provided (150°F-200°F-250°F-350°F). The validation test steps for the extreme expansion are given in Table 10. While for the qualification of the gauge hole packer, the test was conducted at a single temperature of 350°F with a pressure differential of 13,000 psi. The specifications of the extreme and gauge open-hole packers are given in Table 11.

Table 10: Extreme expansion open hole packer testing steps (Mills, et al. 2016)

Step	Temp (°F)	Differential Pressure (psi)
1	250	2,500
2	200	2,500
3	250	5,000
4	350	5,000
5	150	5,000

Table 11: Rating summary of extreme and gauge open hole packers (Mills, et al. 2016)

Rating	Differential Pressure (psi)	Setting (psi)	Temperature (°F)	Cool down (Δ°F)
Extreme Expansion	5,000	2,200	350	200
Gauge Expansion	13,000	2,200	350	-

Suarez, et al. 2017 developed a retrievable packer that can be deployed in deep water applications having the temperature and pressure range of 20,000psi and 450°F (232°C) respectively with an axial load of 900,000 lbs. To release the trapped pressure in the packer element during the retrieval operation slip saver technology was used. Moreover, for the reduction of the stress in the casing due to the slips, the contact area was increased by 300% as compared to the conventional packers. While to decrease the collapse load on the mandrel/body, the distribution of the slip load was made radial instead of tangential. The packer successfully passed the V0 validation test without any leakage and was retrieved successfully.

Table 12: Experimental steps of packer testing (Suarez et al. 2017)

Step	Below Packer (psi)	Above packer (psi)	Temp (°F)	Compression (lbs)	Tension (lbs)
1	20,000		450		350,000
2	16,000		450		600,000
3	0	0	450		800,000
4		12,000	450		850,000
5		20,000	450		350,000
6		20,000	450	250,000	
7		17,500	450	500,000	
8	0	0	450	800,000	
9	15,000		450	900,000	
10	20,000		450	650,000	

Wang, et al. (2020) worked on the packers that failed when installed in the wells located in Kuqa Foreland Basin in Western China. The three reasons that caused the packers to fail were a). precipitation of the drilling mud took place when exposed to high temperatures that blocked the piston chamber, b). pump suffocation happens due to a low clearance gap between the casing and the packer, c). wrong calculation of axial force. The first problem can be solved by scraping the well 50m below and above the setting depth of the casing at least three times. For the second problem, it was suggested that the pump suffocation can be avoided by maintaining the flow rate of the displacement fluid at 3m/s. Moreover, to increase the clearance gap the packer OD was reduced from 108.22mm to 110.74mm. For the last problem, the axial load was reduced by the installation of the expansion joints. After making the adjustments, the newly optimized packer was tested for the V0 validation test with pressure and temperature of 13,053psi and 232°C respectively. While the axial and tension load of 111.13 and 136.05 tons were applied respectively. The packer cleared the V0 validation test and was installed successfully in 43 wells. Figure 2 shows the packer performance curve.

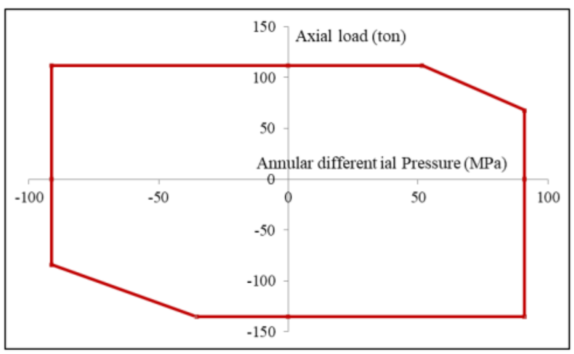

Figure 2: Packer performance envelope cure (Wang, et al. 2020)

8. CONCLUSIONS

This paper compares and discuss the packer testing and qualification procedures for HPHT and complex well situation as a basis for what is necessary to achieve best geothermal well completion.

The grades that are established for the standardization and classification of the conventional packer are not suitable for the packers that have to be installed in the geothermal well. As in those standards, the best grade is V0 in which the testing fluid is air or nitrogen.

In the geothermal reservoir, gases are rarely present but steam exists in subsurface geothermal environments and no such provision of steam in the testing standard was found in the literature.

Secondly, as seen in the grade descriptions and studies by the different authors only one temperature cycle is recommended, and the pressure should be held for only 15 minutes. Whereas, in the geothermal stimulation job more than one temperature cycle is needed.

Our papers shows that the categories that are laid by API and ISO do not address the conditions of the geothermal environment and, therefore, it is required that new standards and classification that is specific to the geothermal packers should be formulated. This will help to improve the workability and reliability of the packers installed in harsh geothermal conditions.

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