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A Comprehensive Study of Cementing Operation for HPHT Geothermal Wells

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ABSTRACT

The most integral and critical part of the geothermal wells are the casing sustainability and integrity of the cementation of the casings. The design procedure of the cementing process should be done intently which includes materials and methods which ensures that the total length or True Vertical Depth (TVD) of both the cased annulus and the open hole annulus is completely filled with required amount of cement without any sort of internal or external leakage which will withstand long term exposure to geothermal fluids and temperature. Geothermal wells experiences High Pressure and High Temperature (HPHT) to sustain and durable in such hostile condition and for good zonal isolation cement design must be taken into account carefully. Downhole performance of cement slurries depends mainly on two parameters viz. Temperature and Pressure influencing the properties such as how these parameters maintains necessary strength to support tubular and how long the slurry will pump. Out of these two parameters, temperature has more pronounced effect as bottom hole temperature maintains the speed of chemical reactions during hydration of cement which ultimately results in cement strength development and cement setting. It is required to know rise in temperature during cement setting. The cementing materials, cement slurry designs, various equipments, and testing methods are outlined and reviewed.

1. INTRODUCTION

Cementing of casing is one of crucial stage in geothermal wells after drilling of high pressure and high temperature formation. When each stage of section is drilled with drill pipe and heavy weight casing is lowered into it. From bulk pressure silos dry cement and additives are mixed with water to design cement slurry. Then cement slurry is pumped down into bottom hole and rises to fill the annular space between casing and formation. Thickening time is provided to cement to cure and prevent the formation of crack in cement wall (Thakar et al., 2018).

The main objective of the any cementing programme is to isolation to the formation and to provide casing strength. And make sure that annulus between casing and formation should be filled with good sound cement. So it can withstand long term duration of geothermal fluids and high temperature and pressure of geothermal wells (Thakkar et al., 2019).

The high thermal stress imposed on casing should be uniformly so that stress concentration is avoided. Unlike conventional oil & gas wells, casing in geothermal wells are run back to surface and are fully cemented back to the surface. Cementation of geothermal wells perhaps most longevity, integrity and critical job of drilling process.

High temperature and pressure geothermal wells are sensitive towards cement slurry, most influence thickening time of slurry. While increase in temperature it reduces the thickening time and cement will set quicker than normal temperature wells.

Also plastic viscosity and yield point decreases with increases in temperature. As increase in well depth causes increase in equivalent circulating density and hydrostatic pressure. Contrarily causes reduction in temperature rising of well due to thermal expansion.

In HPHT geothermal wells temperature variation causes expansion and contraction of casing and it can lead to cracking in cementing. And its physical and chemical behavior also changes significantly at HPHT. Weight of cement should be withstand formation pressure by designing minimum overbalance.

In case of static temperature greater than 110°C, 35% to 40% silica BWOC is added to Portland cements in order to avoid strength retrogression. In case of static temperature exceeding 232°C, perlite, bentonite & diatomaceous earth are more flexible to use rather than adding fly ash to Class J or Portland cement. (Zagreb, 1994)

Cementing Equipments

Cementing equipments divides into two main parts:

1) In hole equipments – Casing accessories

2) Surface Equipment

1) In hole equipments – Casing accessories: - When the casing is run into hole it is equipped with number of equipments to enable cementing operation.

• Casing or Float Shoe: A guide shoe is used to guide casing through the hole and it is fitted or pin end of to first casing. It is heavy walled and round profile unit. it is fitted with non-retuning valve which allow only flow of cement form casing into the well but it is prevent back flow of it and internal structure of it is made up of drillable material.

• Float Collar: A float collar is basically placed at one or two joints above the shoe and it is act as one way valve which allows flow only from casing to annulus. It can also act as landing for cementing wiper plugs. It is usual to use float valve in shoe and float collar for redundancy purposes (Patel et al., 2018).

• Wiper Plugs: Wiper Plugs are used to limit contamination of cement by mud and are run inside the casing. It classified as bottom and top wiper plugs. Bottom wiper plug is designed as hollow central core and covered with diaphragm. Bottom wiper plug wipes off the mud film from the casing walls and then volume of cement slurry passed followed by top wiper plug. When entire volume of cement displaced behind casing top plug reaches the float top of bottom plug.

• Casing Centralisers: To keep casing concentric within the drilled hole and it's fitted on casing string. And it is used to hold the casing off the walls, thus allowing uniformly cement sheath to place around the casing wall.

• Cementing Head: A cementing head is attached to the top of casing string and it is allows the connection from mixing slurry tank. Cementing head is usually designed as it can contain and release plugs.

• Tag-in adaptor and string centralisers: A tag-in adaptor is fitted to the bottom of the cementing string while utilising inner string cementing process. It is used to allow the string to be "stabbed in' in the float collar.

2) Surface Equipment:- Typically surface equipment which are in used for geothermal wells are conventionally same as provided on oil field units like slurry mixing, pumping unit, bulk pressure silos and control system.

• Slurry mixer and puming unit: Slurry mixer which is equipped with automated controlled computer system which can mix the slurry for cementing job and it can pump uniform density slurry at a rate of 800 lpm at high pressure. This slurry mixer is attached with two independently triplex pumps which is in system with electronic density control

• Bulk pressure silos: Bulk pressure silos can hold dry cement which can be transfer directly to the slurry mixing unit and chemicals and additives are directly pumped into dry cement or into liquid slurry via control system.

• Control system: Surface equipments are appropriately attached with control system to host smoothly operation of surface equipments. Thus, in geothermal wells cementing pumping unit system have capacity upto 65,000 liters cement slurry can mix and can pump within admissible cement pumping time.

2. TESTING METHODS OF CEMENT SLURRY

• Thickening time tester: It is an instrument is used to determine pumpability of cement slurry in geothermal wells under high pressure and temperature. It is calibrated in such a way that unit of consistency of slurry in cup can be recorded by voltmeter. So value of consistency can be measure thorough the duration of test. Once the consistency test value reaches a designated value then test is terminated and that time is referred as "Thickening Time". For casing thickening time is normally 2 to 3 hrs. But due to safety constraints an hour is additionally add in thickening time. Thickening time test is performed on bottom hole circulating temperature which is less than bottom hole static temperature.

• Ultra-sonic cement analyzer: Ultra-sonic cement analyzer measures the strength development trend while cement is curing in autoclave. A sample is placed in autoclave and downhole temperature and pressure condition is simulate. The basic theory behind that time required for to travel ultrasonic wave through sample in autoclave. As many as eight samples can be monitored simultaneously allows quick examination of slurry design. The result is completely depends upon strength of cement slurry design which can be plotted against time at any point in test.

• Pressurized fluid density balance: Pressurized fluid density is similar method as conventional mud balance method additionally fixed volume cup under pressure is maintained in this method. Cement often contain trapped air which gives erroneous result while using conventional mud balance equipment but using pressurized fluid density balance equipment air quantity can be reduce by pressurizing the cup to a negligible amount and gives more accurate density of cement slurry.

3. CEMENT SLURRY DESIGN OF GEOTHERMAL WELLS

Cement slurry design is the overall estimation regarding the quantities of additives, gelling times, allowable pumping times slurry yield etc. In order to prepare a cementing program and cement slurry calculations, the prerequisites are estimation of bottomhole static and circulating temperatures at the obtained casing depths with the help from adjacent wells or from scientific survey information, if there are no nearby wells.

Temperature and pressure are two basic influencers on the downhole performance of cement slurries. They affect how long the slurry will pump and how it develops the strength necessary to support the pipe. Temperature has the more pronounced influence bottom hole temperature maintains the speed of chemical reactions during hydration of cement which ultimately results in cement strength development and cement setting.

To obtain the volume calculations for pumping particular cement slurry, there is a common practice to break the volume calculations into different series of volume components which includes

Table 1: Description of Volume Components

Sr. No.	Volume Components	Meaning
1	Casing to open hole annulus volume	Annulus volume between the new casing and the open hole from casing shoe depth till previous casing shoe depth
2	Casing to casing annulus volume	Annulus volume between the new casing and the previous casing
3	Shoe track volume	Fluid volume contained within the casing from the float collar down to the casing shoe
4	Rat hole volume	New open hole volume from the depth of the casing shoe to the total drilled depth

Total slurry volume is calculated as:

Total slurry volume =Shoe track volume + (Casing to open hole annulus volume + Rat hole volume) * (1 + excess) + Casing to casing annulus volume.

Where excess = 1.0 to 1.5 which depends on different conditions.

HPHT wells cementing remedy is described as follows

- Accurate estimation of temperature
- Monitoring of down-hole conditions
- Cementing simulator
- Induced stresses during testing
- Efficient displacement of mud:
  - Proper mud rheology
  - Suitable spacer
  - Rheological hierarchy
  - Wettability change
  - Annular velocity
  - Contact time
  - Density train

Long thickening time, thermal thinning, low rheology, unstable slurry, settling of heavy wright materials, poor displacement, channeling - API fluid loss > 50 ml, high initial consistency- difficult to prepare & pump are the main challenging factors which contributes for poor cementing job for HPHT wells.

For cementing all geothermal wells, mainly Portland cement is used viz. API Class G cement and the necessary characteristics of this cement can decline and the rate of deterioration of it is affected by amount of reactive additives present in the cement slurry, amount of mix water (water/cement ratio) and the temperature to which a set cement is exposed and it is essentially a calcium silicate material which consists mainly dicalcium & tricalcium silicate to which addition of water let these components hydrate forming gelatinous calcium silicate hydrate viz. C-S-H gel which provides required dimensional stability and strength to set the cement. C-S-H gel is an excellent binding material for temperatures ranging below 110°C.

If there are no external disturbances for the cement, then set cement constantly continues to hydrate and ultimately increases the strength pending a year or even longer and at last the strength gets constant and work efficiently.

In high porosity formation, greater permeability of set cement becomes sensitive to corrosive formation fluids becoming a serious problem as equivalent of losing its strength.The real problem lie in the great increase of permeability. Class G cement of the normal density water permeabilities within one month were 10 to 100 times higher than the recommended limit, while in a lower density extended cement they were even higher.(Nelson, 1990)Uniformity of the cement sheath around pipe determines to a great extent the effectiveness of the seal between wellbore and casing.

4 PROPERTIES OF CEMENT SLURRIES

It has been found that circulation of drilling fluids in the well for several hours prior to cementing job may significantly reduces the circulation temperatures which leads to over-estimation of circulation temperatures and a slurry over-retarded. Thus, most geothermal wells are not cemented under geothermal conditions and therefore it’s very important task to design cement slurry for a high temperature well for accurate circulation and static temperature values. Retarders are added to cement slurry which allows required placement time at the maximum circulating temperature, thus at least 2-3 hours of pumping schedule is usually necessary for required placement time. Extenders such as perlite, fly ash and bentonite are usually used for preparing cement slurry of lower density which prevents the loss of cement slurry.

Few intermediate fluids such as chemical wash, wash or spacers are usually pumped into the borehole along with the cement slurry to avoid the formation of channels which are mainly dependent on drilling mud viscosity and deposition of filter cake. For prevention of formation of cement filter cake which causes bridging in the annulus, we need to control the filtration rate during pumping in and usually API fluid loss rate around 50-100 ml/30 min. is satisfactory in most of the primary cementing jobs. Dispersantsare mainly used to the designed cement slurry needs to be pumped in turbulent flow regime.

Table 2 Cementing problems along with its possible technology solutions

Sr. No.	Cementing Problem	Technological solution
1	Micro-annulus Isolation problem	• Can be prevented with the help of squeeze cementing material for occupying the free space excluding bridging during its placement or dehydrating. • Expanding agents are used.
2	High angle (deviation) well	• First approach is to get control over stress on cement or casing by lowering cement channel or with the help of casing centralizer. • Second approach is to opt for different cementing or well designing if first one fails.
3	Interruption in cement sheath	Durability enhancement additives increase the quality of cement sheaths in case of shock stress /vibrations.
4	Gas migration	Cement slurries re modified accordingly by increasing zero gelling time and decreasing time of transition, enhancing slurries compressibility. • By reducing the total column section height. • Latex additives compensate for transition time between solid & liquid stage.
5	High-pressure well/kick-off plug	Highly densed cement ranging up to 25 lbm/gal for plugging and high-pressure zonal isolation is achieved.
6	Changes in P&T throughout well’s life	Flexibility enhancement additives are added for providing higher compressive strengths in case of massive change in stresses.

5. CONCLUSION

For cementing jobs in HPHT geothermal wells, the pre-requisites which are described in this paper must be maintained thoroughly throughout the cementing job in order to meet the desired accuracy. Cements for geothermal wells circumscribe a wide range of composite chemical processes and well bore conditions, thus many factors come into play to decide the particular composition for a particular well condition. Liquid additives which allow lesser mixing time and accurate addition are preferred more in case of cement additives which are not dry blended with the bulk cement. For achieving great control along with most consistent and accurate results for HPHT wells, requirement of large volume of fluids and bath tanks needs to be fulfilled.

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