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ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ISSN: 0976-3376

Asian Journal of Science and Technology
Vol. 08, Issue, 09, pp.5812-5816, September, 2017

RESEARCH ARTICLE

CEMENT SLURRY DESIGN FOR GEOTHERMAL EXPLORATORY WELL IN DHOLERA FIELD USING A NOVEL CONCEPT OF MULTIFUNCTIONAL ADDITIVES

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ARTICLE INFO

Article History:
Received 22nd June, 2017
Received in revised form
04th July, 2017
Accepted 26th August, 2017
Published online 27th September, 2017

Key words:

Geothermal well cementing,
Multifunctional additives,
Hydroxyethyl cellulose,
Dholera field.

ABSTRACT

Perhaps the most critical component of the drilling process to the integrity and longevity of a geothermal well is the cementation of the casings. API class G cement is usually utilized for cementation of geothermal well in India, and additives are used to improve the properties of the cement slurry. The primary aim of cementation of geothermal well is to withstand the well in presence of geothermal fluids and high temperature. The objective of the study is to investigate the effect of cement slurry consistency using hydroxyl ethyl cellulose. This paper includes various aspects of geothermal well cementing and cement slurry design for case study of Dholera geothermal field. Hydroxyethyl cellulose is used as multifunctional additives for getting desired properties of the cement slurry for Dholera geothermal field.

INTRODUCTION

Cement materials are important not only for modern structures and buildings in expanding urban environments and mega projects, but also for a variety of industries including the geothermal and oil production sector, specifically in drilling and completion operations. Well cementing is one of the most important and crucial operations performed in a geothermal well. Geothermal wells are mainly found in the United States, Kenya, Philippines, Indonesia, New Zealand, Iceland, Mexico, Italy, Japan, and other locations (Salim and Amani, 2013a). Geothermal wells used similar techniques as cementation of oil and gas wells. However, challenges arise in geothermal well cementing are corrosive brines (which contains corrosive elements like CO_3^{2-} and SO_4^{2-} ions) and formation gases (like CO_2 and H_2S). These corrosive fluids deteriorate cement and reduce the long-term integrity of geothermal wells. Geothermal wells are exposed to high thermal stresses on casing and cementation is required to uniform stress distribution over the entire length of casing. HPHT well summit survey on biggest technological gaps in HPHT operations held in 2010 and 2012 shows that cement slurry design and performance is a critical

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issue in high-pressure and high-temperature operations (Salim and Amani, 2013b). Sometimes during cementation of geothermal well, there is possibility of water flow into the cement column which increases water cement ratio and it could cause cracks in cement matrix. Hence, cementation of high-temperature geothermal wells is a challenging job.

Problems occurred in geothermal well cementing

High Temperature

When temperature exceeded above the 110°C, Portland cement starts losing its compressive strength. The significant loss of compressive strength occurred within one month after cementation operation. This phenomenon is known as strength retrogression (Swayze, 1954). Tricalcium silicate and dicalcium silicate hydrates with the addition of water forms C-H-S phase which is stable and excellent binding material upto 110°C. Figure 1 indicates that above 110°C C-H-S phase convert to Tobermorite, Xonotlite or Truscottite which is unstable products and have low compressive strength. To avoid this problem increases C/S ratio by adding 35-40% silica BWOC so that C-H-S phase convert to α–C_2SH phase which is stable phase above 110°C and consists of high compressive strength (Iverson *et al*., 2010). Retarders must be added in cement slurry to increase the thickening time so that cement

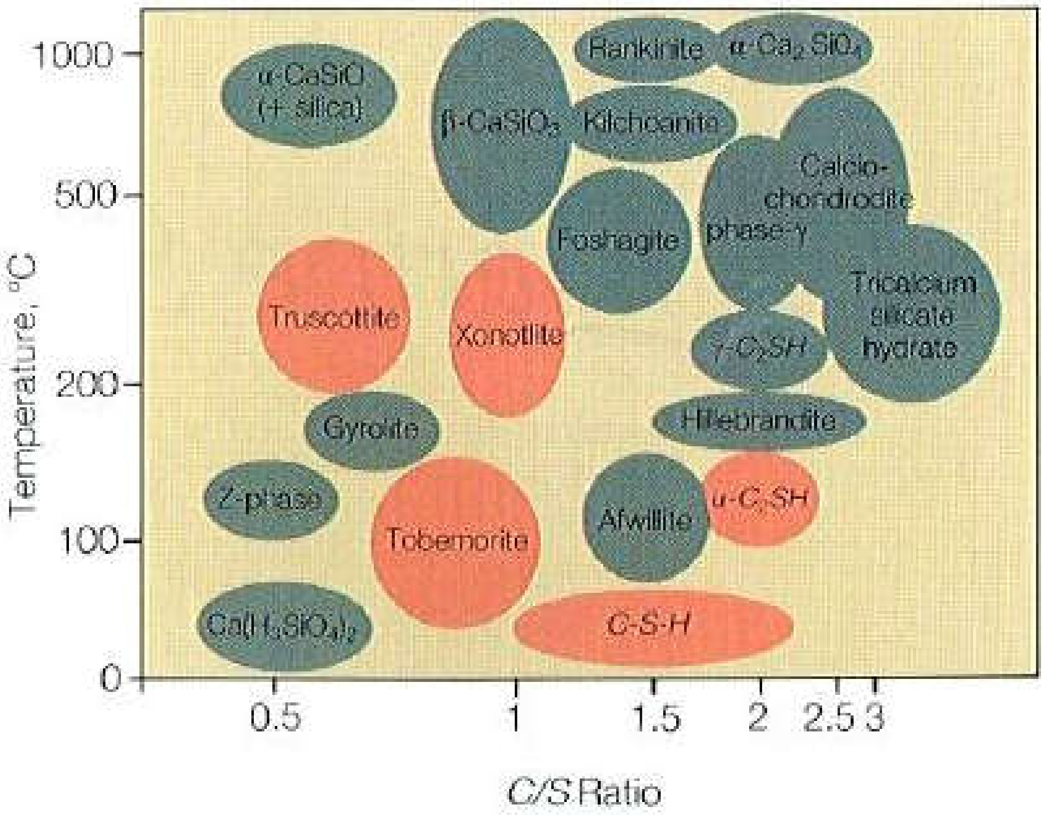

Figure 1. Cement Phase Change Diagram (Michaux, 1989)

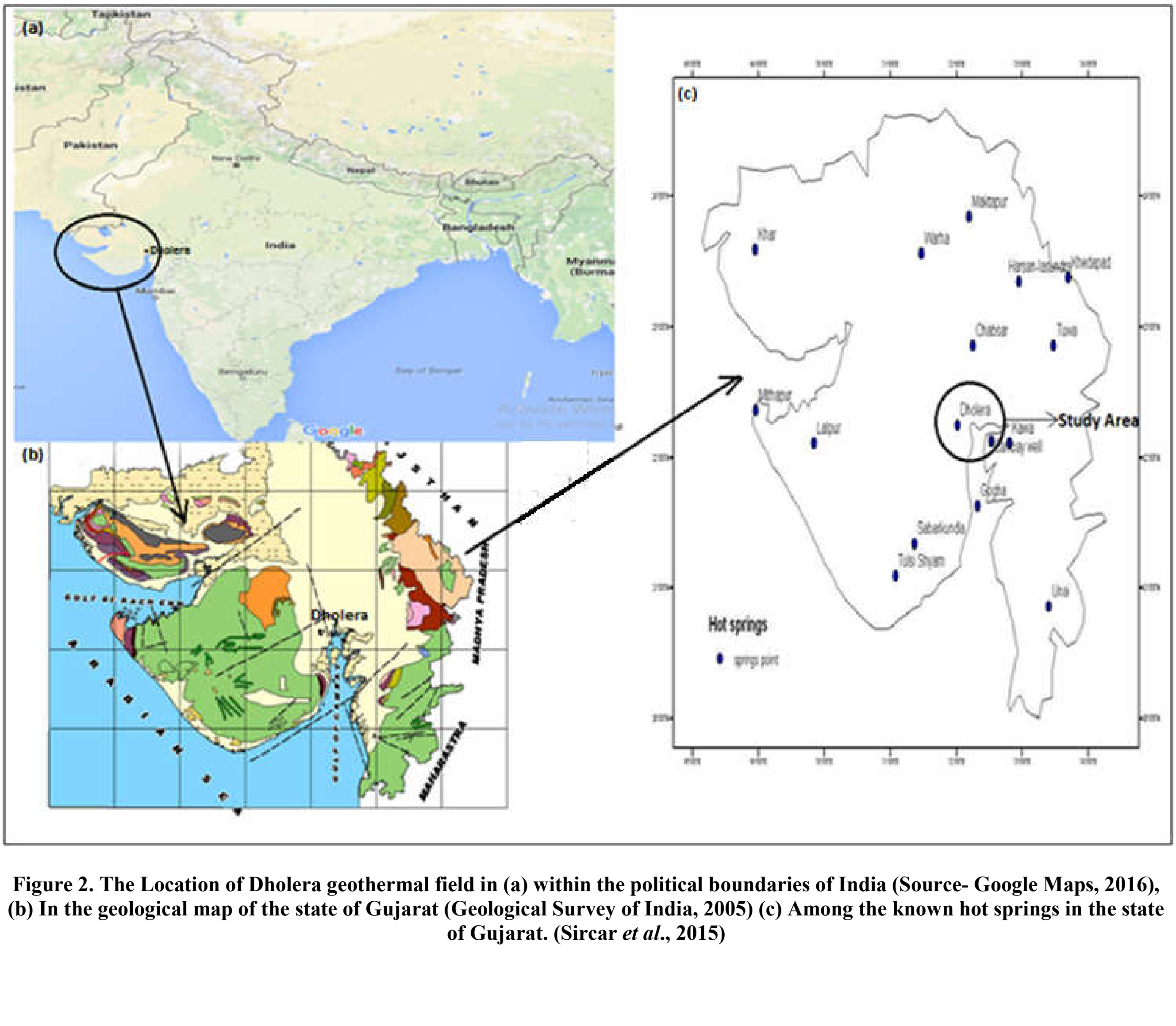

Figure 2. The Location of Dholera geothermal field in (a) within the political boundaries of India (Source- Google Maps, 2016), (b) In the geological map of the state of Gujarat (Geological Survey of India, 2005) (c) Among the known hot springs in the state of Gujarat. (Sircar *et al*., 2015)

slurry is in pumpable condition until it achieved the desired position at elevated downhole temperature. High Alumina cement is used when formation temperature reaches to 400°C for providing more stability.

Corrosive Environment

Casing corrosion is occurred due to the corrosive element (like CO_2) present in formation. Cement carbonation is common problem occurred in high-temperature geothermal wells. Shen and Pye (1989) shows the effect of CO_2 attack on cement in high-temperature geothermal wells and also provide an example of casing ruptures and failures of geothermal well in Broadlands field, New Zealand. Analysis of geothermal wells shows that cement carbonation depends on the amount of CO_2, temperature and cement additives.

Lost Circulation

The main difference between oil well and geothermal well is surrounding environment. Surrounding formation of geothermal well is poorly consolidated and sometimes highly fractured with low fracture gradient (Nelson and Eilers, 2006). Hence lost circulation in formation is a common problem occurred during geothermal well cementation. Cement slurry unable to reach the surface due to loss of cement slurry during cementation operations which leads to costlier remedial operations. To minimize the lost circulation problem, lightweight cement slurry is prepared by using extenders like fly ash, bentonite. Extenders are used to reduce the density of cement slurry for jobs where the cement column hydrostatic head exceeds the fracture strength of the formation. It also reduces the amount of cement required for cementing job because extenders increase the volume of cement slurry (Broni-Bediako *et al*., 2016; Rabia, 2002). For high fractured zone, density of cement slurry maintained below 12.5 ppg using foamed or microsphere extended cement. Bour and Rickard (2000) mentioned the application of lightweight foamed cement on Hawaiian geothermal well to prevent lost circulation.

Fluid Loss

If cement slurry loses water before it reaches to projected position in the annulus, then its pumpability reduces and adversely affects the water sensitive formation. Compressive strength is also reduced if the fluid loss is high. Tolerated fluid loss amount relies on the cement slurry formulation and type of cement job but normally 50-100 ml/30min is recommended fluid loss rate (API RP 10B, 2005). Thick filter cake formation leads to the differential pipe sticking problem. Generally, filter cake can be removed by chemical or mechanical practices. Chemical practice means dissolving filter cake by pumping the chemicals like acid, brines, enzymes, Ethyl-lactate ester or a combination of these. While mechanical means remove filter cake using reciprocating or rotating scratcher mounted on casing.

Case Study

Dholera geothermal field is located in the Ahmedabad district of Gujarat state. The Dholera geothermal field is an ancient port city in Gulf of Khambhat (as shown in Figure 2) lies 30 km South-West of the Dhandhuka village in the Ahmedabad district and is around 60 km to the North of the city of Bhavnagar. The Dholera springs were first discovered over a century ago. The first drilled well in this area flows an appreciable rate of about 6 to 7 litres per second. A total of four springs have been demarcated in a radius of 4 km, viz. Dholera, Uthan, Swaminarayan temple and Bhadiyad. Of all identified hot springs in Gujarat, the springs in the areas around Dholera have the highest geothermal flow rate in Gujarat (Vaidya *et al*., 2015). The area of study falls on the western margin of the Cambay basin. Cambay basin rests on the Deccan trap, which lies at a depth of 500-600 m. Quaternary alluvial deposits of a thickness up to 100 m occur by the side of the basin (Sircar et at, 2015). The subsurface lithology of the area is mostly sand dominant consisting of alternating layers of coarse and fine sand. The alkaline magnetism causes presences of granitic basement rocks and a shallow mantle (Shah *et al*., 2017).

MATERIALS

For this research the cement used was Class G cement and distilled water**.** Powered form of HEC was used in this study. HEC is a high viscous polymer and hence used in a small proportion in cement slurry. The additional additives including friction reducer (CFR-3), trifunctional additive(D-121) and antifoaming agent (D-AIR 4000L) used with class G oil well cement and water.

Table 1. Case Study Input Data

Well No.	Dholera A03
Type of Job	8’’ Casing cementation
Well Depth (m)	1000
Casing Size	8”
Hole Size	12.5’’
BHST (°C)	105 °C
BHCT (°C)	90°C (Test Temp.)
Specific gravity of mud	1.90
Type of Cement	Class G Portland Cement
Mixing Fluid	Water
Raising Time (Min)	28 minutes
Thickening Time (Min)	140 min (To achieved 70 BC)
API Fluid Loss (ml/30 min)	<50ml/30 min
Free Fluid %	Nil

According to the requirement of the operator mentioned in Table 1, the following slurry composition was prepared to suit the given conditions.

Table 2. Designed Slurry Composition

Selected Slurry Composition	
Component	Weight Percentage
Cement	100
Water	44
HEC	0.25
FR	0.5
D-121	0.1
D-AIR 4000L	0.1

The selection of additives weight percentage is based on trial and error method for achieving desired cement properties. Initially, select additives weight percentage by judgment and experience. If this additives proportion satisfies all user requirements, this set of additives and cement mixture is suitable for attaining field requirement. In case there is any deviation from the desired results, based on judgment change the proportion of additives and repeat all test and evaluate the additives proportion which achieved desired results. Repeat this iteration until desired slurry properties are achieved. After performing number of tests to get desired results cement slurry composition is finalized as shown in Table 2.

As the cement thickens, the torque increases on the spring-loaded potentiometer connected to the paddle shaft. This torque is recorded as a Direct Current (DC) voltage across a resistor on top of the potentiometer. The actual viscosity of the cement can then be derived from a linear plot of DC volts

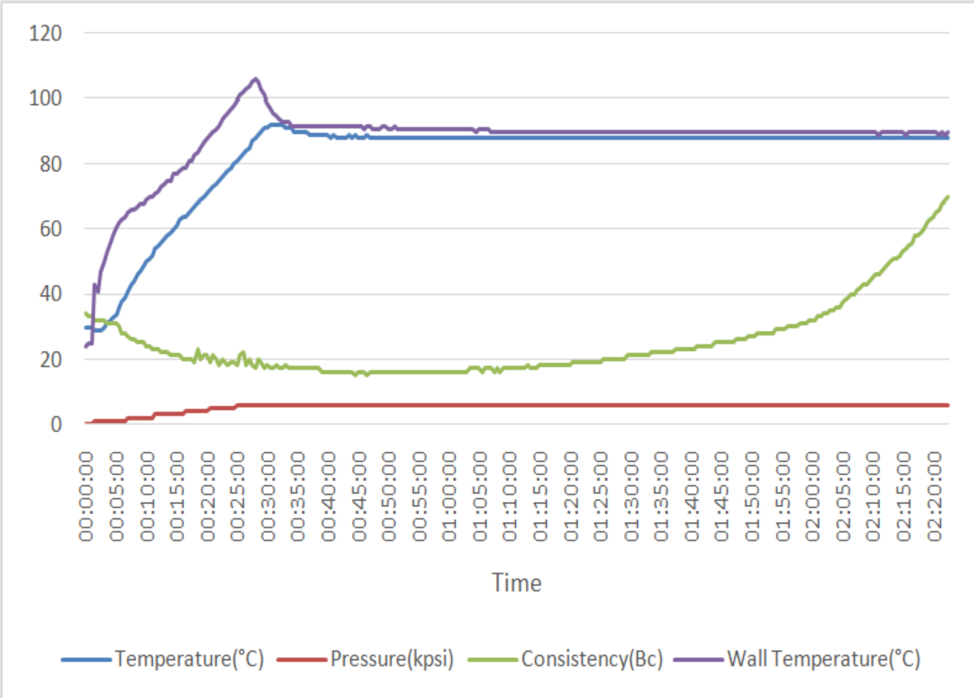

Figure 3. Consistometer Test Result

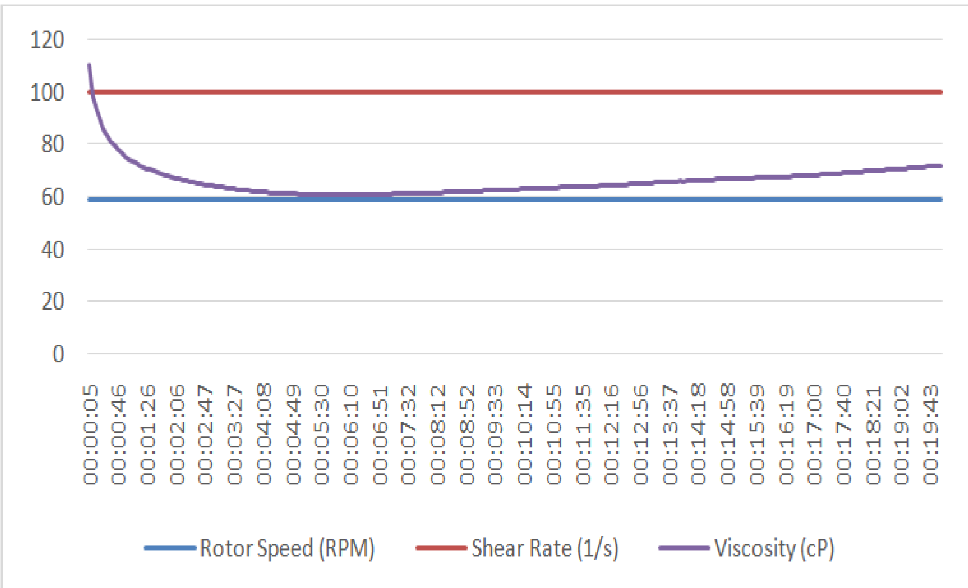

Figure 4. Viscosity of cement slurry

METHODS

This study was carried out in 2017 at Drilling Cementing and Stimulation Centre, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India.

HPHT consistometer: The measuring of thickening time, as determined in a high temperature, high-pressure consistometer, is related to the torque being placed on a stationary paddle within the rotating slurry cup.

versus viscosity in Bearden Units of Consistency (BC). Thickening time test was performed following API 10A Schedule 5 and API RP 10B document was used as guidelines to do the thickening time test (American Petroleum Institute, 1997).

Viscometer: The rotational viscometer used for the research was Fann Viscometer.

Fluid Loss Cell: The static fluid loss cell was used for this research activity.

RESULTS

All experiments were conducted based on the American Petroleum Institute (API) specifications (API RB 10B-2, 2005; API Recommendation 10A, 2005). Table 3 shows the results observed after carrying out laboratory tests with the selected slurry composition based on the well details and job parameters provided by the operator.

Table 3. Test Results

Test Results	
Thickening Time	140 min (To achieved 70 BC)
Specific Gravity	1.85
API Free Water (%v/v)	0 ml in 250 ml of slurry (0%)
Fluid Loss (ml/30min)	30.98
Compressive strength (psi)	2652.6 After 24 hr 4180.29 After 48 hr

Figure 3 shows the consistometer test result graph over a period which is required to achieve consistency of 70 BC. Thickening time recorded here is around 140 minutes. It is a quite stable thickening time for this particular temperature-pressure condition as per API standards. Fluid loss test was also carried out in static condition to measure the loss of formation fluid at lab scale. The fluid was measured around 31 ml/ 30 min which is quite stable for geothermal well drilling operations for Dholera geothermal field. For the same proportion of cement slurry, Figure 4 gives the test result of rheological properties over duration of 20 minutes. Rheology of the cement is important because it characterizes various properties such as, cement paste, grout, and mortar to understand their performance in practical applications. This viscosity result is quite satisfactorily for particular geothermal well applications.

Conclusion

This research has discovered a new method to utilize viscometer, fluid loss cell and consistometer to closely reproduce what is happening to cement slurry during cementing job. HEC is act as a multifunctional additive and reduces numerous single function cement additives.HEC works as a cement slurry viscosifier, free water control agent, fluid loss control agent, extender, and retarder. HEC also improves early and total compressive strength of cement matrix. The cost of polymer based cement slurry is much lower than the conventional cement slurry and suitable for geothermal well cementing. The results produced are quite satisfactory and may be utilized for the upcoming geothermal exploratory well in Dholera geothermal field, Gujarat, India.

Nomenclature

API	American Petroleum Institute
Bc	Bearden unit of consistency
HEC	Hydroxyethyl Cellulose
FLC	Fluid Loss Control
FR	Friction Reducer

Acknowledgement

The authors wish to thank Pandit Deendayal Petroleum University for giving permission to perform experiments in Drilling, Cementing and Stimulation Research Center, Gandhinagar, India. The authors are also thankful to Dr. B. R. Ambedkar Regional Geoscience Laboratories, ONGC, Vadodara, India for support and guidance in this research. Special Thanks to Mr. Ravindra Kumar Jain and Mr. Sunil Kumar Jain for their guidance, advice, criticism, encouragements, and insight throughout the research.

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