"SLURRY DESIGN FOR VERTICAL SHALE WELLS"

A Dissertation submitted
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To
Department of Earth Science & Petroleum Engineering
In partial fulfillment of the requirement for the
Award of the Degree
Master of Technology in Petroleum Exploration
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CERTIFICATE

This is to certify that Mr. Md. Abdus Salam & Mr. Antaryami Singh Goondi have completed M.Tech dissertation entitled **“SLURRY DESIGN ON VERTICAL SHALE WELLS”**under our guidance and supervision. To the best of our knowledge, present work is the result of their original investigation and study. No part of the dissertation has ever been submitted for any other degree or diploma at any university.

This dissertation is fit for the submission and the partial fulfillment of the condition for the award of M.Tech – Petroleum Exploration.

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DEDICATED
TO
OUR GRAND PARENTS

ACKNOWLEDGEMENT

First of all with great humanity, we would like to thank **God**, the almighty who has been too merciful & compassionate for His blessings which have enabled me to pen these words.

We feel highly privileged to express our heartfelt indebtedness to our revered supervisor Dr Kishori Lal & Mr. Rajiv Singhal, Chief Chemist, Department of Cementing Lab (R&D) of Institute of Drilling Technology, Dehradun, and Dr. Pushpa Sharma, Professor, Department of Petroleum Exploration of University of Petroleum and Energy Studies, Dehradun for their judicious and skillful guidance, unreserved help, perpetual energy, enthusiasm, sustained encouragement, close supervision and ever willing help lent to us throughout the tenure of this work.

We would like to thank Mr. K.K. Pratap ED-Head of Institute of Drilling Technology, Mr. M.P. Sinha GM, Head Cementing (R&D) TG & Mr. S. Banik DGM (M) – Head- FTG, ONGC Academy, Dehradun allowing us to do our Project in this prestigious institute. Also we would like to thank the rest of Cementing lab team for their encouragement, comments, help & support and for their technical assistance at every step.

Besides above, we would like to thank the rest of our dissertation committee for their encouragement, insight comments, constructive criticism and difficult questions. We are also thankful to Dr. D.K. Gupta H.O.D., Dr. Mandira Aggarwal, Course Coordinator, Department of Earth Sciences and Petroleum Engineering, Dehradun for providing necessary facilities for research.

We also express our heartily thank to Dr. Sri Hari, Vice Chancellor, Dr. Kamal Bansal, Dean of University of Petroleum and Energy Studies, Dehradun for providing us such great atmosphere for these professional courses.

Our deepest gratitude goes to our family for their unflagging love and support throughout of our life; this dissertation is simply impossible without them. We would like to thank our parents for giving birth to us at first place and supporting us spiritually throughout our life. We can never forget their boundless love, sacrifice, constant inspiration, emotional support, encouragement & blessing brought us where we are today. Our parents unending shower of blessing kept us moving easily with all the hazards vanishing miraculously.

All my not be mentioned but none is forgotten.

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Dated:

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Abstract

The world is facing two energy problems in the medium to long term, climate change and peak oil. Compared to the news about new discoveries, the depleting oilfields are on the rise. Major oil companies are going farther into the ocean to dig deeper in their quest for the fossil fuels. A few have even started their exploration activities in the Arctic Ocean. Difficult geographical locations seem to be the norm for the exploration companies, increasing the costs of the operations and hence the costs of fossil fuel itself.

With such a grim outlook for the future, shale gas can ease the demand pressure, at least temporarily. The past decade has seen the natural gas price peak, renewing the interest in development of 'unconventional' gas resources, such as coal-bed methane, tight gas, and shale gas. In India too, energy 'demand vs. supply' gap has increased the focus on developing all possible energy sources. Unconventional gas resources, including shale gas has the potential to contribute significantly for a few decades. Shale is the common name for rock that was once layers of clay or mud. Due to geological circumstances, these layers were compressed into a fine-grained sedimentary rock. The gas which is trapped in this rock formation is called shale gas. In terms of its chemical makeup, shale gas is typically a dry gas primarily composed of methane.

Several production-enhancement processes are useful in shale-gas reservoirs:

- Prospect evaluation and core testing.
- Shale lithotyping to determine key characteristics of productive shale.
- Log data integration and analysis specific to shale.
- Designing and drilling the vertical and horizontal well for stimulation.
- prop pant size and loading considerations.
- Optimization and tailoring water-frac fluid chemistry to the shale.

Adopting the best practices in cementing shale gas well, Remedial treatment processes for obtaining long-term sustained production. Constructing a suitable cement sheath around the horizontal section of a shale well is a key element in the process of successful fracture-stimulation of shale-gas zones. Conventionally cemented wells did not provide adequate zonal isolation and allowed fracturing fluid to communicate along the horizontal casing. This condition caused targeted intervals to receive less than the designed volume of stimulation fluid and proppant. Tensile strengths and mechanical properties of foamed cements make them ideal for zonal isolation in shale gas. In India one of the ONGC field, Ankleshawer wells #GNSGA, GNSGB & GNSGC tried for shale gas but due to poor cementation good CBL/BDL could not archived. The same problems was evaluated by optimized cement slurry design with various special type cement additives at CMT (R&D) TG lab and data of the same is highlighted in the report .

Authors

Brief View:- ONGC (Oil and Natural Gas Corporation Limited)

In 1955, Government of India decided to develop the oil and natural gas resources in the various regions of the country as part of the Public Sector development. With this objective, an Oil and Natural Gas Directorate was formed. In 1956 directorate raised to the status of commission with enhanced powers.

The directorate was converted in statutory body by an act of parliament. So ONGC was setup to explore oil and natural gas resources in the country.

Since its inception, ONGC has been important in transforming the country's limited upstream sector into a large viable playing field, with its activities spread throughout India and significantly in overseas territories. ONGC went offshore in early 70's and discovered a giant oil field in the form of Bombay High, now known as Mumbai High.

With the liberalized economic policy, adopted by the Government of India in July 1991, ONGC was re-organized as a limited Company under the Company's Act, 1956 in February 1994.

ONGC's objective

- Optimize production of hydrocarbons.
- Self-reliance in technology.
- Promoting indigenous effort in oil and gas related equipment, material and services.
- Assist in conservation of hydrocarbons, more efficient use of energy and development of alternative sources of energy.
- Develop scientifically oriented and technically component human resources through motivation and training.
- Environment protection.
- Generate adequate resource for reinvestments.

ONGC is engaged in E&P activities both in Onshore and Offshore. The Corporation is now venturing out to new areas i.e. deep-water exploration and drilling, exploration in frontier basins, marginal field development, optimization of field development plan field recovery and other allied areas of service sector. ONGC has recognized the need to expand its business through profitable ventures related to petroleum and energy sectors by entering into joint ventures with other Indian and foreign companies. ONGC-Joint venture group (ONGC-JVG) has been formed to give impetus to joint venture activities in areas other than E&P.

As India's principal energy company, ONGC will continue to play a significant role in guaranteeing the country's long term energy security. India is already the world's sixth largestenergy consumer and imports close to 70% of its oil needs. Given India's current rate of economic growth hovering around 7% annually these needs are unlikely to diminish.

So in the main avenue of increased demand all possible ways to increase production by enhanced oil recovery techniques has become the major strategic development path for ONGC.

About IDT

The Institute of Drilling Technology (IDT) was set up in 1978 at Dehradun. Located in the picturesque valley between the green Shivaliks& lower Himalayas it is engaged in relentless efforts in R&D and has rendered excellent services in the areas of Oil & Gas well drilling technology. Over the years institute has emerged as a premier R&D Centre at South East Asia, capable of providing advanced technical knowledge through training.

Fig No. 1

The institute with highly qualified & experienced scientists & engineers carries out applied research in all facets of drilling related activities to achieve technical excellence in R&D efforts & assimilation of emerging technologies. The renowned well control school at IDT has been accredited by International Well Control forum, The Netherlands, International Alliance for Well Control, the Netherlands & also from International Association of Drilling Contractors, USA.

The infrastructure for applied R&D has been developed with the state-of-the-art equipment's& machines to achieve qualitative experimental results. Focus of R&D is directed towards drilling technology, drilling fluid engineering & cementation & cementing materials to meet the challenges of drilling industry. The technologists & scientists provide solutions to the down-hole drilling problems, improving design of the systems & thereby contributing towards the development of excellent, efficient & cost effective operations.

.Introduction

The world is facing two energy problems in the medium to long term, climate change and peak oil. Compared to the news about new discoveries, the depleting oilfields are on the rise. Major oil companies are going farther into the ocean to dig deeper in their quest for the fossil fuels. A few have even started their exploration activities in the Arctic Ocean. Difficult geographical locations seem to be the norm for the exploration companies, increasing the costs of the operations and hence the costs of fossil fuel itself.

With such a grim outlook for the future, shale gas can ease the demand pressure, at least temporarily. The past decade has seen the natural gas price peak, renewing the interest in development of 'unconventional' gas resources, such as coal-bed methane, tight gas, and shale gas.

In India too, energy 'demand vs. supply' gap has increased the focus on developing all possible energy sources. Unconventional gas resources, including shale gas has the potential to contribute significantly for a few decades. Shale is the common name for rock that was once layers of clay or mud. Due to geological circumstances, these layers were compressed into a fine-grained sedimentary rock. The gas which is trapped in this rock formation is called shale gas. In terms of its chemical makeup, shale gas is typically a dry gas primarily composed of methane.

In many organic shale reservoirs, the natural gas is stored as free gas in fractures. All rocks have pore space that can hold water or gases. In Shale, the grains fit together so tightly that there is little movement of water or gas through the rock. In order to release the gas, especially in commercial quantities, the shale must either have natural fractures, or fractures must be created in the rocks to provide suitable permeability.

Things changed for the better in the 1990s.When using a new extraction technology, a tight shale deposit could be cracked open by injecting water into the formation at high pressure. Water is mixed with sand to keep the cracks open and therefore increase the permeability of the formation, enabling the gas to flow. Shale deposits have limited depth but cover a large region. Vertical drilling could only capture a zone of 20-30 meters and therefore only a small amount of gas could be produced per well. Over the past couple of decades, the drilling techniques evolved and horizontal drilling is possible today.

Primarily three factors have come together in the recent past to make shale gas more attractive,

- Advancements in the horizontal drilling technology
- Advancements in the hydraulic fracturing technology
- A surge in the natural gas prices in the past few years as a result of significant demand pressures

USA has revolutionized the shale gas and is responsible for technological and economical advantages in the shale gas production today. This shale gas revolution has turned USA from a gas

importing country to a gas exporting country (to Japan). 90% of the global shale gas is currently produced by the USA.United States Shale gas basins (Source: Shale Gas Primer, US DOE, 2009)
There are technical difficulties in producing gas from shales, which have ultralow permeabilities and vary in brittleness. Multi-layered shale reservoirs have widely varying reservoir characteristics and flow mechanism regimes .Formations typically have high capillary pressures in hydraulic fracturing scenarios. Treatment fluids can potentially damage shale formations .Multilayered shale reservoirs with a variety of reservoir characteristics require specialized evaluation and drilling techniques and “next-well” geological, seismic, and production comparisons to identify optimum fracturing targets. All of these data sources can be fed into custom models for a potential well’s production design. Combining logging systems with next-well and
Field-wide properties, geo mechanics, and production performance data forms
the basis of an advanced modelling system. The system is tailored for the specific
Shale-production mechanism and composition of the proposed new well’s drilling and completion design. Placing the well’s target location is critical and can be done with economical, simplified, rotary-steerable drilling assemblies in land-based shale wells.
Determining proper fracture placement

Shale technologies

Several production-enhancement processes are useful in shale-gas reservoirs:• Prospect evaluation and core testing.• Shale lithotyping to determine key characteristics of productive shale.• Log data integration and analysis specific to
shale.• Designing and drilling the vertical and horizontal well for stimulation.
• Proppant size and loading considerations.• Optimization and tailoring water-frac fluid chemistry to the shale.• Remedial treatment processes for obtaining
Long-term sustained production.

Cementing shale wells

Constructing a suitable cement sheath around the horizontal section of a shale well is a key element in the process of successful fracture-stimulation of shale-gas zones. In recent exploration and production activity in Oklahoma’s Woodford shale, wells cemented with foamed cement produced an average of 23% more peak gas than wells cemented with conventional slurries. Conventionally cemented wells did
not provide adequate zonal isolation and allowed fracturing fluid to communicate
along the horizontal casing. This condition caused targeted intervals to receive less than the designed volume of stimulation fluid and proppant. Tensile strengths and mechanical properties of foamed cements make them ideal for zonal isolation in shale gas .

In India one of the ONGC field Ankleshawer well #GNSGA tried for shale gas but due to poor cementation good CBL/BDL could not archived. The same problems was evaluated by optimised cement slurry design with various cement additives at CMT(R&D) TG lab and data of the same is highlighted in the report .

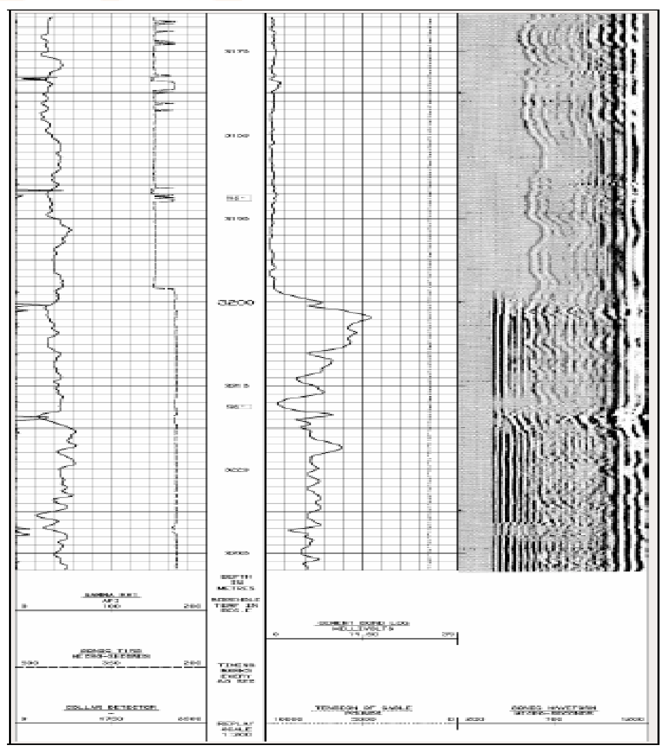
Cement is typically a fine powder of alumina, silica, lime, iron oxide etc. These raw materials are extracted from the quarry crushed to a very fine powder and then blended in the correct proportions.

This blended raw material is called the 'raw feed' or 'kiln feed' and is heated in a rotary kiln where it reaches a temperature of about 1400 C to 1500 C. In its simplest form, the rotary kiln is a tube up to 200 meters long and perhaps 6 meters in diameter, with a long flame at one end. The raw feed enters the kiln at the cool end and gradually passes down to the hot end, then falls out of the kiln and cools down.

It is a hydraulic binder, i.e. it hardens when water is added. Thus, they can harden underwater or when constantly exposed to wet weather. The chemical reaction results in hydrates that are not very water soluble and thus are quite durable in water.

Cementation is an activity in drilling operation which is done to isolate the wells. While doing cementation in the vertical wells, many problems have been seen when checked in the CBL logs such as weak bonding between cement and the shale formation, low compressive strength of the cement etc. We need to optimize cement slurry which can overcome these problems. In this case, three shale wells have been taken from Ankaleshwar Asset. The slurry has been designed by adding the proportionate additives to the cement slurry. The composition of cement and additives is as per the availability at site. In our experiments, the main challenge is to designed that slurry which will give us good thickening time @ 30 Bc, good rheology parameters, good compressive strength & stability.

Cement bond log (CBL): These have become the standard method of evaluating cement jobs since they not only detect the presence of cement, but also indicate how good the cement bond is. The CBL tool is run on wireline and emits sonic signals. The signals pass through the casing and are picked up by a receiver. The distance between transmitter and receiver is about 3ft. The logging tool must be centralised in the hole to give accurate results. Both the time taken for the signal to reach the receiver, and the amplitude of the returning signal, give an indication of the cement bond.



Since the speed of sound is greater in casing than in the formation or mud, the first signals, which are received, are those that travelled through the casing. If the amplitude is large (strong signal) this indicates that the pipe is free (poor bond). When cement is firmly bonded to the casing and the formation the signal is attenuated, and is characteristic of the formation behind the casing. The signal can also indicate where the cement is bonded to the casing, but not the formation.

Reasons of Poor Cement Job

The main cause for poor cement jobs are:

- The presence of mud channels in the annulus. These channels of gelled mud are not displaced by the cement slurry and result in poor bonding between the casing and formation. When mud is being displaced from the annulus the flow pattern may not be uniform.
- If the pipe is not properly centralised the highest resistance to flow occurs where the clearance is least. This is where mud channels are most likely to occur.
- Improper contact time of formation with the cement slurry. Field tests shown that for a good cement bond to develop the formation should be in contact with the cement slurry for a certain time period while the cement is being displaced. The recommended contact time (pump past time) is about 10 minutes for most cement jobs.

Recommendations for a good Cement Job

- Use centralisers, especially at critical points in the casing string;
- Move the casing during the cement job. In general rotation is preferred to reciprocation, since the latter may cause surging against the formation. A specially designed swivel may be installed between the cementing head and the casing to allow rotation. (Centralisers remain static and allow the casing to rotate within them);
- Before doing the cement job, condition the mud to ensure good flow properties (low PV, low YP) so that it can be easily displaced;
- Displace the cement under turbulent conditions. (This may not be practicable in large diameter casing where the high pump rates and pressures may cause erosion or formation breakdown);
- Use spacers to prevent mud contamination in the annulus.

DIFFERENCE B/W CONSTRUCTION & OIL WELL CEMENT

- Particle size of oil well cement is finer than construction cement.
- Percentage of Tri calcium aluminate is 15% in oil construction cement and 3% in oil well cement.
- Oil well cement is High Sulphate Resistant (HSR) whereas construction cement is not HSR.
- Strength of construction cement is less than oil well cement.

Classes of oil well cement

API has recommended nine classifications of oil well cement which are- A, B, C, D, E, F, G, H, J. These are further divided into three categories of ordinary, moderate & high sulphate resistant depending upon the Tri Calcium Sulphate.

- **Class A**
  - Depth surface – 6000 ft (1830 m).
  - No special properties.
  - Similar to ASTM C 150, Type I.

- **Class B**
  - Depth surface – 6000 ft (1830 m).
  - Moderate to high sulphate resistance.
  - Similar to ASTM C 150 Types II.

- **Class C**
  - Depth surface – 6000 ft (1830 m).
  - High early strength.
  - Moderate to high sulphate resistance.
  - Similar to ASTM C 150 Types III.

- **Class D**
  - Depth from 6000 ft – 10,000 ft (1830 m - 3050 m).
  - Moderate and high sulphate resistance.
  - Moderately high pressure and temperature.

- **Class E**
  - Depth from 10,000 ft – 14,000 ft (3050 m - 4270 m).
  - Moderate and high sulphate resistance.
  - High pressure and temperature.

- **Class F**
  - Depth from 10,000 ft – 16,000 ft (3050 m - 4270 m).
  - Moderate to high sulphate resistance.
  - Extremely high pressure and temperature.

- **Class G**
  - • Depth surface – 8000 ft (2440 m), as basic cement, fine.
  - • Can be used with accelerators and retarders for other specifications.
  - • Moderate to high sulphate resistance.
  - • No addition other than calcium sulphate or water.

- **Class H**
  - • Depth surface – 8000 ft (2440 m), as basic cement, course.
  - • Can be used with accelerators and retarders for other specifications.
  - • Moderate to high sulphate resistance.
  - • No addition other than calcium sulphate or water.

- **Class J**
  - • Depth 12,000 – 16,000 ft (3660 m - 4880 m)
  - • Extremely high pressure and temperature.
  - • Can be used with accelerators and retarders for other specifications.
  - • Moderate to high sulphate resistance.
  - • No addition other than calcium sulphate or water.

Note: - ONGC recommends Class G type cement for cementation activities, mainly this cement is provided by Dalmiya& Dig-Vijay cement companies.

CEMENTATION

Oil well cementation is the process of mixing and displacing a slurry down the casing and up the annulus, behind the casing, where is allowed to "set", thus bonding the casing to the formation.

Some additional functions of cementation include:

- Protecting producing formations
- Providing support for the casing
- Protecting the casing from corrosion
- Sealing off troublesome zones
- Protecting the borehole in the event of problems

How Does Cementing Work?

Part of the process of preparing a well for further drilling, production or abandonment, cementing a well is the procedure of developing and pumping cement into place in a wellbore.

Used for a number of different reasons, cementing protects and seals the wellbore. Most commonly, cementing is used to permanently shut off water penetration into the well. Part of the completion process of a prospective production well, cementing can be used to seal the annulus after a casing string has been run in a wellbore. Additionally, cementing is used to seal a lost circulation zone, or an area where there is a reduction or absence of flow within the well. In directional drilling, cementing is used to plug an existing well, in order to run a directional well from that point. Also, cementing is used to plug a well to abandon it.

Cementing is performed when the cement slurry is deployed into the well via pumps, displacing the drilling fluids still located within the well, and replacing them with cement. The cement slurry flows to the bottom of the wellbore through the casing, which will eventually be the pipe through which the hydrocarbons flow to the surface. From there it fills in the space between the casing and the actual wellbore, and hardens. This creates a seal so that outside materials cannot enter the well flow, as well as permanently positions the casing in place as shown in Fig 2.

Preparing the cement

In preparing a well for cementing, it is important to establish the amount of cement required for the job. This is done by measuring the diameter of the borehole along its depth, using a caliper log. Utilizing both mechanical and sonic means, multi-finger caliper logs measure the diameter of the well at numerous locations simultaneously in order to accommodate for irregularities in the wellbore diameter and determine the volume of the open hole.

Additionally, the required physical properties of the cement are essential before commencing cementing operations. The proper set cement is also determined, including the density and viscosity of the material, before actually pumping the cement into the hole.

Special mixers, including hydraulic jet mixers, re-circulating mixers or batch mixers, are used to combine dry cement with water to create the wet cement, also known as slurry. The cement used in the well cementing process is Portland cement, and it is calibrated with additives to form one of eight different API classes of cement. Each is employed for various situations.

Additives can include accelerators, which shorten the setting time required for the cement, as well as retarders, which do the opposite and make the cement setting time longer. In order to decrease or increase the density of the cement, lightweight and heavyweight additives are added. Additives can be added to transform the compressive strength of the cement, as well as flow properties and dehydration rates. Extenders can be used to expand the cement in an effort to reduce the cost of cementing, and antifoam additives can be added to prevent foaming within the well. In order to plug lost circulation zones, bridging materials are added, as well.

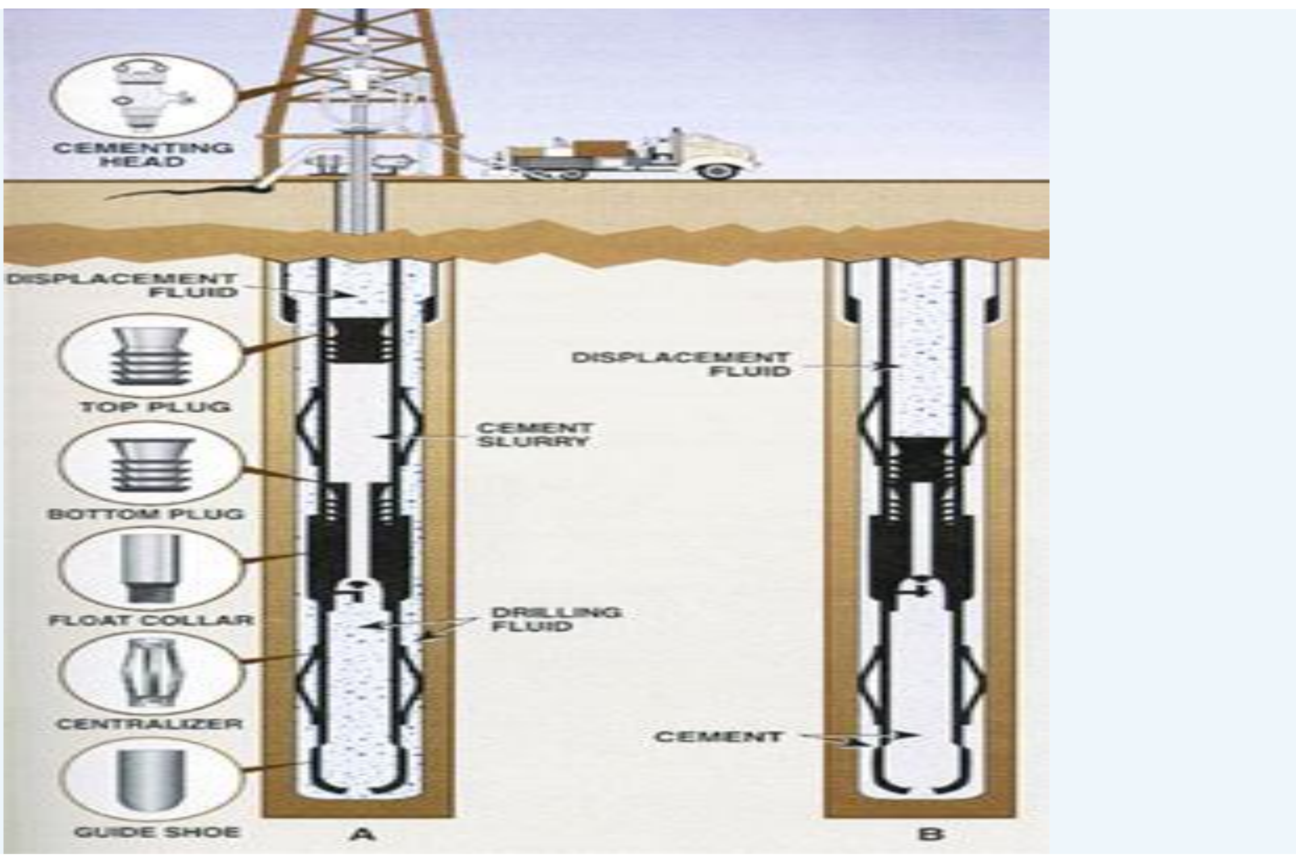


Fig No. 2 - Cementation operation at site

Cementing the well

After casing, or steel pipe, is run into the well, an L-shaped cementing head is fixed to the top of the wellhead to receive the slurry from the pumps. Two wiper plugs (Fig3), or cementing plugs, that sweep the inside of the casing and prevent mixing: the bottom plug and the top plug.

Keeping the drilling fluids from mixing with the cement slurry, the bottom plug is introduced into the well, and cement slurry is pumped into the well behind it. The bottom plug is then caught just above the bottom of the wellbore by the float collar, which functions as a one-way valve allowing the cement slurry to enter the well.

Then the pressure on the cement being pumped into the well is increased until a diaphragm is broken within the bottom plug, permitting the slurry to flow through it and up the outside of the casing string.

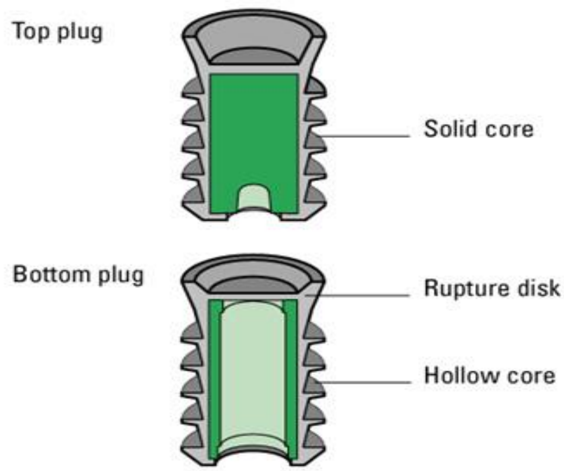


Fig No. 3 - Plugs

After the proper volume of cement is pumped into the well, a top plug is pumped into the casing pushing the remaining slurry through the bottom plug. Once the top plug reaches the bottom plug, the pumps are turned off, and the cement is allowed to set.

The amount of time it takes cement to harden is called thickening time or pump ability time. For setting wells at deep depths, under high temperature or pressure, as well as in corrosive environments, special cements can be employed.

Cement Additives

Most of the cement slurries contain some additives which modifies the property of slurry to get desired slurry parameters. Some of the cement additives are:-

- Accelerators
- Retarders
- Extenders
- Dispersants
- Fluid loss control agents
- Pozzolans
- Weighing agents

Accelerators

An accelerator is a chemical additive used to speed up the normal rate of reaction between cement and water which shortens the thickening time of the cement, increase the early strength of cement, and saves time on the drilling rig. Cement slurries used opposite shallow, low-temperature formations require accelerators to shorten the time of their setting.

Most operators wait on cement to reach a minimum compressive strength of 500 psi before resuming drilling operations. When using accelerators, this strength can be developed in 4 hours. It is a good practice to use accelerators with basic cements because at temperatures below 100 Deg F, neat cement may require 1 or 2 days to develop a 500 psi compressive strength. Common accelerators are:-sodium metasilicate, sodium chloride, sea water, anhydrous calcium chloride, potassium chloride and gypsum.

Retarders

Neat cement slurries set quickly at a BHT greater than 110 ^{0}F. A retarder is an additive used to increase the thickening time of cements. Besides extending the pumping time of cements, most retarders affect the viscosity to some degree. The governing factors for the use of retarders are temperature and depth.

Common retarders are lignosulfonates, modified cellulose, organic acids, organic materials and borax.

Extenders

Extended cement slurries are used to reduce the hydrostatic pressure on weak formations and to decrease the cost of slurries. Extenders work by allowing the addition of more water to the slurry to lighten the mixture and to keep the solids from separating. These additives change the thickening times, compressive strengths and water loss.

Common extenders are fly ash, bentonite, and diatomaceous earth.

Pozzolans

Pozzolans are natural or artificial siliceous materials added to Portland cement to reduce slurry density and viscosity. The material may be either a volcanic ash or clay high in silica. The silica in the pozzolans combines with the free lime in dry cement, which means a soluble constituent is removed from the cement and the new cement is made more resistive.

Common pozzolans are diatomaceous earth and fly ash.

Dispersants

Cement-slurry-flow properties are complicated and do not exemplify the fluidity of ideal Newtonian fluid behavior. The thinning effects of dispersants can help modify slurry rheology for easier mixing and placement. Rheology is a measure of both the resistance to flow and a reduction in the resistance to flow under pressure. Adding dispersants can lower friction and lower pressure during pumping, enhance turbulent flow at reduced pumping rates, and allow operators to mix densified cement slurries. Dispersants can also be used to help reduce pressure exerted when placing cement across unconsolidated sands, depleted or weak formations, possibly preventing lost circulation.

Some of them are:-

CD-32, CFR-3, DO-65.

Fluid loss control agents

Fluid loss control additives are designed to reduce water loss from the slurry to the formation. This protects sensitive formations from damage and avoids premature dehydration of the slurry, giving better results in squeeze jobs. In a narrow annulus, if the loss of fluid to the formation is excessive, a layer of filtrate will build up on the walls causing reduced flow and increased friction pressures due both to the restricted flowpath and the higher viscosity of the slurry. Some fluid loss control additives also act as gas migration control additives. These prevent gas from channeling through the slurry as it sets and the hydrostatic load is reduced.

Commonly used are:- HALAD-567, HALAD-4, HALAD-9.

Weighing agents

Weighting agents are normally required to produce cement slurry of high specific gravity. The main requirements for weighting agents are:

- The specific gravity is greater than the cement
- The particle size distribution is consistent
- They have a low water requirement
- They are chemically inert in the cement slurry

Some of the common weighing agents are:- Barite, Hematite, Sand.

Effect of additives in conventional slurry design

- **Addition of set accelerators(calcium chloride)**
    - Thickening time controlled
    - Fluid loss increased
    - Poor rheology
- **Addition of fluid loss additives**
    - Fluid loss controlled
    - Thickening time increased
    - Poor rheology
- **Addition of dispersants**
    - Thickening time increased
    - Fluid loss improved
    - Rheology improved

Difficult to control all 3 parameters simultaneously.

Slurry design parameters

Some of the crucial parameters in designing slurry are:-

- Specific gravity
- Thickening time
- Fluid loss/ filtration loss
- Free water
- Rheological parameters
- Compressive strength
- Stability (in specific cases)

- **Specific Gravity**

Specific gravity is one of the most important properties of cement slurry. Slurry additives and amount of water added determines the specific gravity of slurry.

Normally specific gravity of slurry is kept higher than mud for facilitating displacement of drilling fluid from annulus. The specific gravity difference of 0.2- 0.5 g/cc is normally recommended between mud and cement slurry.

Specific gravity of cement slurry is adjusted to:-

- Counter balance the formation pressure.
- Control the loss of slurry in week zone.
- Facilitate the effective mud removal.

Fig No. 4 – Mud Balance

The density or weight of a given volume of liquid is determined by using a mud balance. The arm is graduated & permits an accurate measurement to within ± 0.1 pounds per gallon or ±0.01 sp. gravity. The balance is constructed so that the fixed volume cup at one end of the beam is balanced by a fixed counterweight at the opposite end with a sliding weight rider free to move along the graduated scale. A level bubble mounted on the beam indicates when the system is in balance. Fig No. 4.

PROCEDURE:

- Place the mud balance base on a flat level surface.
- Fill the clean, dry cup to the top with the freshly obtained mud sample to be weighed.
- Place the lid on the cup & set it with a gentle twisting motion. Be sure that some mud is the hole in cap to ensure the removal of trapped air or gas.
- Cover the hole in the lid with a finger & wash all mud from the outside of the cup & arm. Then thoroughly dry the entire balance.
- Place the balance on the knife edge & move the rider along the outside of the arm until the cup & arm are balanced as indicated by the bubble.
- Read mud weight at the edge of the rider toward the mud cup.
- Clean & dry the mud cup after each use.

- **Thickening Time**

The thickening time is defined as the time required for the cement slurry to reach the limit of 100 Bearden units (BC) of consistency.

It is a measurement of time during which a cement slurry remains in a fluid state and is capable of being pumped. Thickening time is assessed under simulated down-hole conditions using a consistometer that plots the consistency of slurry over time at the anticipated temperature and pressure conditions.

Excess thickening time is avoided because:-

- Annular rings against permeable zones cause gas migration.
- It cause water pockets and hence severally affects the quality of cementation

The apparatus used is High Pressure High Temperature (HPHT) Consistometer and consists of rotating cylindrical slurry container equipped with a stationary paddle, all enclosed in a pressure vessel capable of withstanding well stimulation pressure and temperature, potentiometer which is used to measure the Bc of the slurry, a thermocouple is inserted into the container which helps us to measure the temperature of the slurry as shown in Fig No. 5.

Fig No. 5 - HPHT Consistometer

- **Fluid Loss**

The design properties of slurries are significantly influenced by the water content. Thus, slurries that lose water can also be subject to a loss or degradation of design properties. It can lead to annulus plugging, incomplete displacement, annulus leakage, etc.

There are a number of conditions that can induce fluid loss:

- Water being drawn from the slurry into the permeable formation, in particular when pumping has ceased and the slurry is static, but not yet set

Displacing or squeezing water from the slurry as it passes through constrictions such as tight clearance between the casing and the annulus

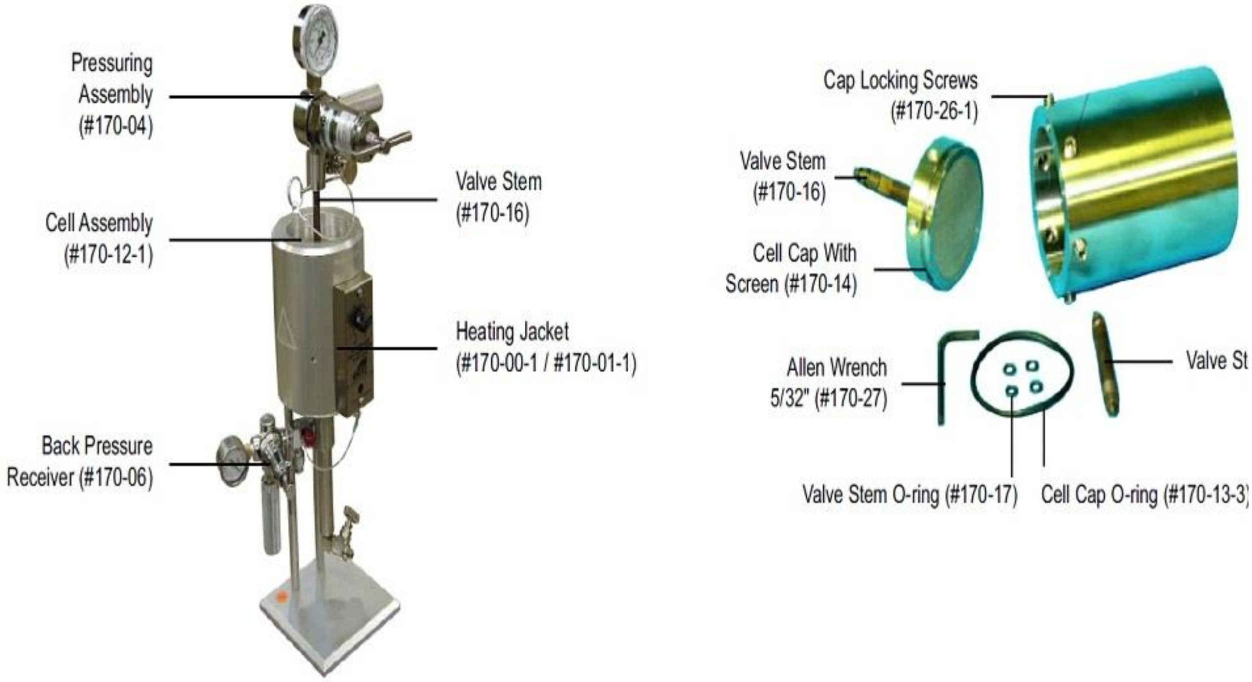


Fig No. 6

HPHT filter presses are designed to for testing drilling fluids & cement under elevated temperatures & pressures. This simulates various down-hole conditions & provides a reliable method for determining the effectiveness of material being tested. The complete assembly consists of the following

- A controlled pressure source
- Two pressure regulators
- A high-pressure test cell
- A heating jacket for heating the test cell
- A suitable stand

$$\text{Fluid loss} = \frac{84.84 * (Vt)}{t^{1/2}} \qquad \text{……………………(i)}$$

Where:-

Vt =Volume of fluid collected in milli-litres

t=time required in seconds

Note:- This formula is used only when 't' comes out to be 30 minutes. If it continues then fluid loss is twice of the volume collected.

- **Stability**

Stability is an important parameter. Cement slurry stability is a major requirement for successful oil well cementing, especially in high angled and horizontal wells. If the slurry is not stable it means that the particles are not suspended uniformly. The specific gravity difference between various regions of slurry must be within 0.02- 0.05.

- **Free Water**

The aqueous phase that is separated from a slurry or mixture of fluids. In cementing operations, free water is undesirable since channels tend to form through the set cement, providing potential gas migration paths. In processing reservoir fluids, the water that separates easily under gravity separation is known as free water. In some cases, additional water may be locked in an emulsion, contributing to the aqueous phase but not available as free water.

- **Rheology** There are various characteristics that are determined by using rheological parameters & these are

(a) Ability to suspend & carry cuttings to the surface.
(b) To analyze the effect of drilled solids contaminants, chemicals & temperature.
(c) To calculate surge & swab pressures.

Rheological parameters are measured by using "Fann V.G Meter" which is a direct reading concentric cylinders rotary device to determine shear stresses & different shear rates i.e. 600 & 300 rpm.

There are various rheological parameters that are necessary to be studied ,when working with HPHT drilling fluids & these are,

1) **APPARENT VISCOSITY (AV):** The shear stress divided by shear rate (at any rate of shear) is called effective or apparent viscosity at a given point. It is measured in centipoises.

$$AV = \theta_{600}/2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(ii)}$$

2) **PLASTIC VISCOSITY (PV):** It is a measure of flow resistance caused by the interaction of solids in the drilling fluids expressed in centipoises. This should be as low as reasonably possible to minimize ECD.

$$PV = \theta_{600} - \theta_{300} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(iii)}$$

3) **YIELD POINT (YP):** It is a measurement of internal resistance caused by electrical environment of the particles & is expressed in lbs/100ft^2. It should be sufficient to prevent sag but not so high to cause gelation or high surge & swab pressures.

$$YP = \theta_{300} - PV \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(iv)}$$

Fig No. 7

- Fann viscometers are direct reading instruments which are available in six-speed & twelve-speed designs for use on either 50Hz or 60 Hz electrical power as shown in Fig No. 7.
- These are used in research & production and are recommended for evaluating the rheological properties of fluids, Newtonian & non-Newtonian.
- These viscometers are 'Couette rotational viscometers' in which the test fluid is contained in the annular space between the outer cylinder & the bob (inner cylinder) & the viscosity is measured.

- **Compressive strength**

  SIGNIFICANCE

  - The strength developed by cement depends on various factors such as water cement ratio, temperature, time and additives used . For testing purpose it is necessary to define all these conditions.
  - The minimum compressive strength required to hold the casing and to seal the formation is 500psi. Compressive strength of set cements mass increases with time and temperature. API recommends a maximum pressure of 3000psi, probably because higher pressures are having very little effect on compressive strength during hydration process.

Fig No. 8 HPHT CURING CHAMBER

Fig No. 9 VERSATESTER

TEST

1. The slurry is first prepared and then poured in to moulds in an evenly distributed pattern and paddling is done using a spatula to minimize segregation .The excess slurry is removed.

2. The moulds are now placed in a curing chamber and the desired temperature and pressure is applied .The specimens are then removed and allowed to cool.

3. The specimen is then tested in a compressive loading machine where load is applied on the blocks. The load at which material failure takes is noted and knowing the cross sectional area of that specimen the compressive strength of that block can be determined**.**

- **Ultrasonic Cement Analyzer (UCA)**

This is the first equipment of its kind in ONGC. With the help of this equipment it is possible to determine compressive strength development of a cement slurry sample while it is being cured under down hole conditions. Cement slurry, prepared as per API procedure is placed under simulated down hole curing condition in an autoclave unit. An ultrasonic signal is transmitted through the sample as it hardens. Variation in the ultrasonic signal’s transit time through the sample is measured by a microprocessor and correlated with the strength development. In conventional method, first a mould is prepared form the cement slurry under down hole condition. The mould is then crushed by strength testing machine. In this way compressive strength can be determined at the end of the curing period only and no real time observation of strength development is possible. This shortcoming of conventional method is completely eliminated by using UCA by which a real time observation vs. time is possible.

Fig.No. 10 –Ultrasonic Cement Analyzer (UCA)

- **GAS Migration Test Apparatus(GMA)**

This equipment is used for designing of gas tight cement slurry and evaluation of its gas tight properties. Here mainly N2 is used for applying pressure in the container.

Fig. No. 11 –Gas Migration Apparatus (GMA)

Shale
Shale is a fine-grained sedimentary rock that forms from the compaction of silt and clay-size mineral particles that we commonly call "mud". This composition places shale in a category of sedimentary rocks known as "mudstones". Shale is distinguished from other mudstones because it is fissile and laminated. "Laminated" means that the rock is made up of many thin layers. "Fissile" means that the rock readily splits into thin pieces along the laminations.

Oil Shale
Oil shale is a rock that contains significant amounts of organic material in the form of kerogen. Up to 1/3 of the rock can be solid kerogen. Liquid and gaseous hydrocarbons can be extracted from oil shale but the rock must be heated and/or treated with solvents. This is usually much less efficient than drilling rocks that will yield oil or gas directly into a well. Extracting the hydrocarbons from oil shale produces emissions and waste products that cause significant environmental concerns. This is one reason why the world's extensive oil shale deposits have not been aggressively utilized.

Shale Sample

Oil shale is a rock that contains a significant amount of organic material in the form of solid kerogen. Up to 1/3 of the rock can be solid organic material. This specimen is approximately four inches (ten centimeters) across.

Oil shale usually meets the definition of "shale" in that it is "a laminated rock consisting of at least 67% clay minerals," however; it sometimes contains enough organic material and carbonate minerals that clay minerals account for less than 67% of the rock.

Composition of Shale
Shale is a rock composed mainly of clay-size mineral grains. These tiny grains are usually clay minerals such as illite, kaolinite and smectite. Shale usually contain other clay-size mineral particles such as quartz, chert and feldspar. Other constituents might include organic particles, carbonate minerals, iron oxide minerals, sulfide minerals and heavy mineral grains. These "other constituents"

in the rock are often determined by the shale's environment of deposition and often determine the color of the rock.

Hydraulic Properties of Shale

Hydraulic properties are characteristics of a rock such as permeability and porosity that reflect its ability to hold and transmit fluids such as water, oil or natural gas.

Shale has a very small particle size so the interstitial spaces are very small. In fact they are so small that oil, natural gas and water have difficulty moving through the rock. Shale can therefore serve as a cap rock for oil and natural gas traps and it also is an aquiclude that blocks or limits the flow of groundwater.

Although the interstitial spaces in shale are very small they can take up a significant volume of the rock. This allows the shale to hold significant amounts of water, gas or oil but not be able to effectively transmit them because of the low permeability. The oil and gas industry overcomes these limitations of shale by using horizontal drilling and hydraulic fracturing to create artificial porosity and permeability within the rock.

Some of the clay minerals that occur in shale have the ability to absorb or adsorb large amounts of water, natural gas, ions or other substances. This property of shale can enable it to selectively and tenaciously hold or freely release fluids or ions.

Engineering Properties of Shale Soils

Shale's and the soils derived from them are some of the most troublesome materials to build upon. They are subject to changes in volume and competence that generally make them unreliable construction substrates.

Expansive Soils

The clay minerals in some shale-derived soils have the ability to absorb and release large amounts of water. This change in moisture content is usually accompanied by a change in volume which can be as much as several percent. These materials are called "expansive soils". When these soils become wet they swell and when they dry out they shrink. Buildings, roads, utility lines or other structures placed upon or within these materials can be weakened or damaged by the forces and motion of volume change. Expansive soils are one of the most common causes of foundation damage to buildings in the United States.

Scope of Work:

- Study of problem being faced in cementing in vertical shale well
- To use some methodology that must avoid the week cementing in these wells.
- Comparison between the physical properties of the slurries like fluid loss, rheology and compressive strength using other materials which may be responsible for the week bonding between shale formation and cement.
- Design of cement slurry with improved physical properties with indigenous sources.

Project Objective:

The objective of this project is to design slurry which will make the good bond with the shale formation fulfilling all physical parameters.

Project Planning: -

- Problem Faced in Cementation in Vertical Shale wells.
- Experimental work with indigenous resources chemicals.
- Comparison and analysis between problematic solutions and improved suggested methodology.
- Conclusion and recommendation to be drawn from the study.

Problem Faced in Cementation in Vertical Shale wells.

- Weak Bonding between Shale formation and cement.
- Low compressive strength of cement in shale zone.
- Instability between cement and shale formation.
- Fulfilling the physical parameters as per the requisition.

Experimental work with indigenous resources chemicals:-

The following materials were required to carry out the experimental work in Laboratory to overcome the above problems and as per requisition: -

- API Class G Cement (Digvijay).
- KCl / Alkophine
- Cement Additives (Silica Flour, Silica fume, Suspend HT, Gas Stop HT, H-447, CFR-3, HR-12and NTDP).

Requisition for well to Design Cement Slurry: -

Requisition for well GNSGA, Ankleswar: -

(A) Well Details and Job Parameters:-

(1)	Type of Job	: 7" Cementation.
(2)	Depth (meters)	: 3800M.
(3)	Bit Size / Casing Size	: 8.1/2" X 7"Casing.
(4)	Cement Rise	: 1100M
(5)	Specific Gravity of Mud	: 1.42gm/cc.
(6)	Bottom Hole Static Temp (BHST)	: 150^o C (As per GTO) at 3800M.
	Note: 221^o F Recorded at 2958.5M as per Log 9 5/8".	
(7)	Bottom Hole Circulating Temp (BHCT)	: 116^{o}C.
(8)	Specific Gravity of Cement Slurry	: 1.90 gm/cc.
(9)	Time to reach Temp & Pressure	: 40min.
(10)	Break in Pumping of Cement Slurry i. 1st Break of 10 min after 75min. ii. 2nd Break of --- min after --- Min.	
(11)	Thickening Time needed	: at 30BC, (220Min).
(12)	Consistency Data	: To be provided.
(13)	API Free Water	: Nil/Traces.
(14)	Fluid Loss	: Less than 50ml.
(15)	Rheological data:- i. P.V. /Y.P. to be provided. ii. N' / K' to be provided. iii. Critical Velocity (meter /sec).	
(16)	Compressive Strength	: After 24 hours & 72 hours.
(17)	Tentative Date of Job	:00/00/00.

Remarks:

(B) Details of Samples: -

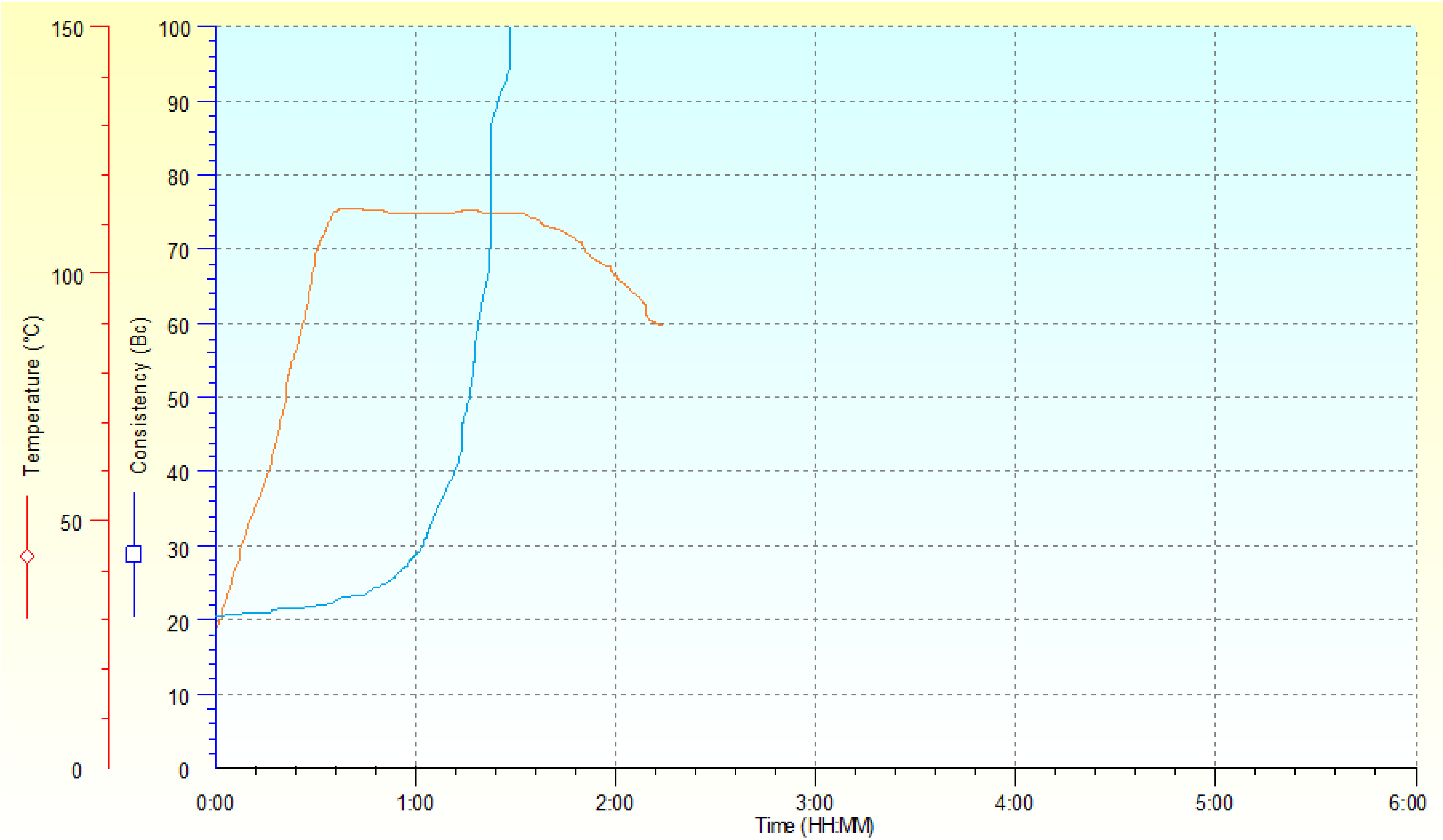
(18)	Type of Cement & Lot No.	: OWC Digvijay Make Lot-2014
(19)	Water	: 3GPL water.
(20)	Cement Additives to be used for gas tight blended Cement Slurry: (Considering Silica Flour = 33% Dry Blended).	
(21)	Cement Additives Available a'. Halad 413 b. Suspend HT (May be dry blended) c. HR-12 d. D AIR 4000L e.Other additives available (Gas Stop HT & HR-5).	

Experiments: - Slurry design composition details for well GNSGA, Ankleshwar

Slurry Design Composition 01 for GNSGA well dated 25-02-2015 @ Consistometer No. 06: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 52 33 5 Kcl + H447 + S.HT (Dry B) + 3 1 0.8 CFR-3 + HR-12 + Gas Stop HT + 0.4 0.5 0.5 nTBP 0.1	Temp -116°C, Pr- 10,000psi, R/T- 40min, 10min break after 75minutes	Min	30Bc at 220min	77min	Thickening time is less than the requirements. Need to increase retarder and decrease the accelerator.
2.	Sp. Gravity		-	gm/cc	1.92	1.92	
3.	Free Fluid		116°C	%	Nil	Nil	
4.	Fluid Loss		At 90°C / 1000 psi	ml/30 min	<100		
5.	Rheology		90°C	Cp, lb/100 sqft	Pv Yp Vc		
6.	Compressive Strength		150°C, Pr. 3000 R/T 24hrs	Psi	After 24 hours After 72 hours		
7.	Stability		120°C	gm/cc	Top Bottom		

Table No. 1



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100
50
0
Temperature (°C)
100
90
80
70
60
50
40
30
20
10
0
Consistency (Bc)
0:00
1:00
2:00
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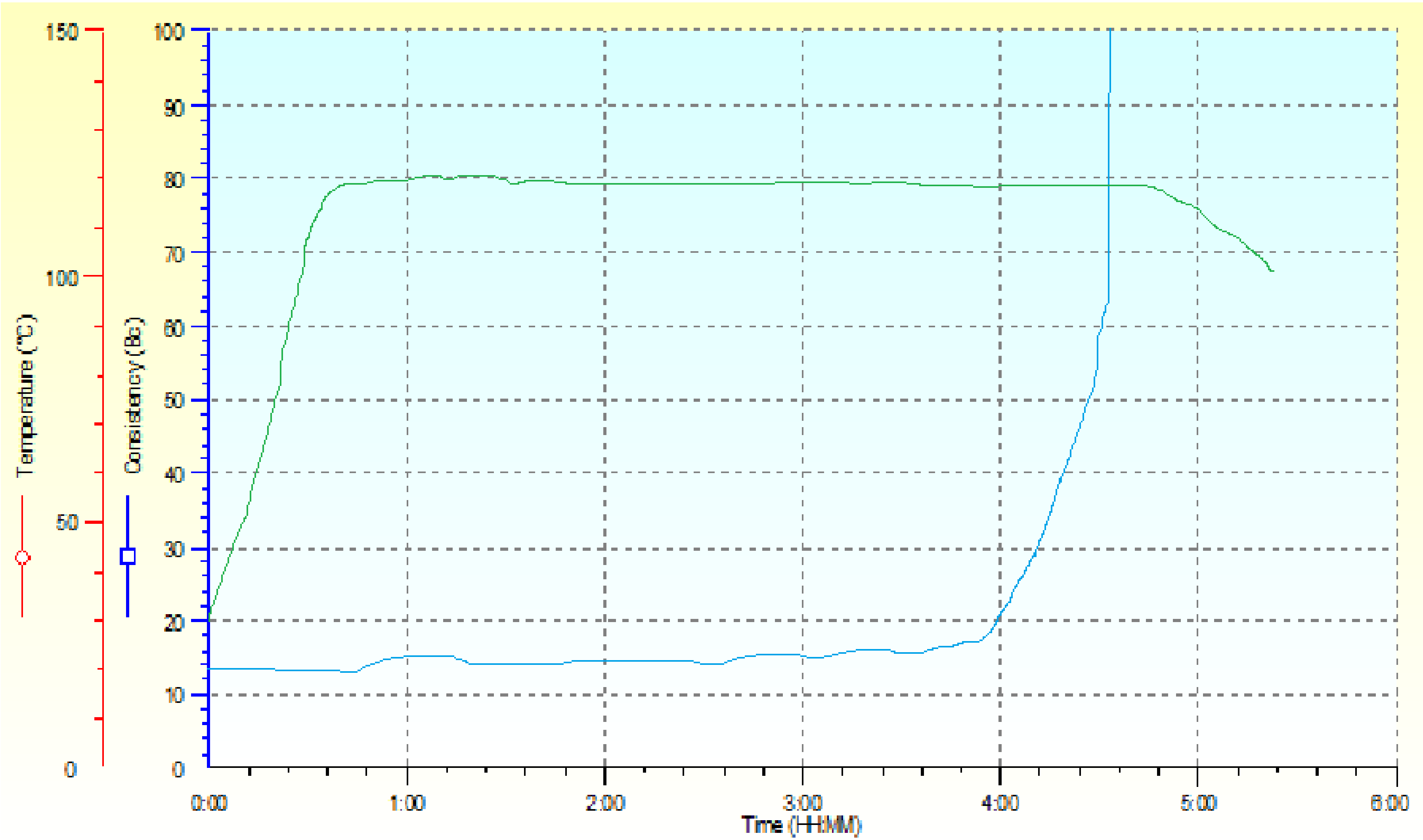
4:00
5:00
6:00
Time (HH:MM)

Graph No. 1

Slurry Design Composition 02 for GNSGA well dated 26-02-2015 @ Consistometer No. 05: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 52 33 5 Kcl + H447 + S.HT (Dry B) + 1 1 0.8 CFR-3 + HR-12 + Gas Stop HT + 0.4 0.5 0 nTBP 0.1	Temp -116^{o}C, Pr- 10,000psi, R/T- 40min, 10min break after 75minutes	Min	30Bc at 220min	277min	Thickening time is in the range. Initial Consistency =15Bc, 30Bc at265min 100Bc at277min Thickening time is increased as % of retarders are increased as compared to previous composition
2.	Sp. Gravity		-	gm/cc	1.92	1.92	
3.	Free Fluid		116^{o}C	%	Nil	Nil	
4.	Fluid Loss		At 90^{o}C / 1000 psi	ml/30 min	<100		
5.	Rheology		90^{o}C	Cp, lb/100 sqft	Pv Yp Vc		
6.	Compressive Strength		150^{o}C, Pr. 3000 R/T 24hrs	Psi	After 24 hours After 72 hours		
7.	Stability		120^{o}C	gm/cc	Top Bottom		

Table No. 2

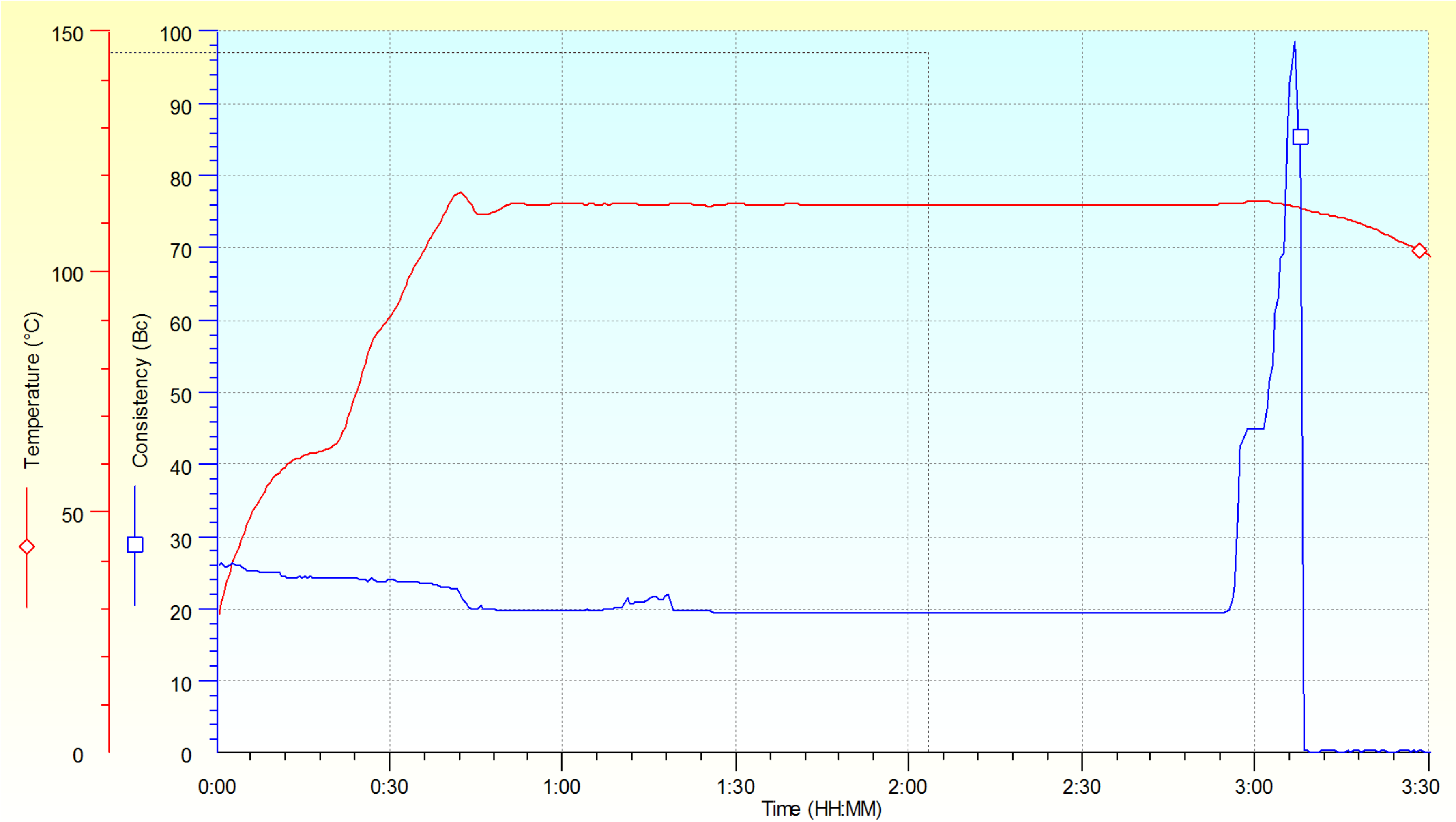

150
100
50
0
Temperature (°C)
Consistency (Bc)
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph No. 2

<u>Slurry Design Composition 03 for GNSGA well dated 27-02-2015 @ Consistometer No. 04: -</u>

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + Sio_2 + SF + 100 52 33 5 Kcl + H447 + S.HT (Dry B) + 0 1 0.8 CFR-3 + HR-12 + Gas Stop HT + 0 0.5 0.5 nTBP 0.1	Temp -116°C, Pr- 10,000psi, R/T- 40min, 10min break after 75minutes	Min	30Bc at 220min	189min	Thickening time is less than the requirements. Need to increase retarder and decrease the accelerator. Here Kcl is zero and CFR-3 which is a dispersant, is zero and reduces turbulence at lower displacement rates
2.	Sp. Gravity		-	gm/cc	1.92	1.92	
3.	Free Fluid		116°C	%	Nil	Nil	
4.	Fluid Loss		At 90°C / 1000 psi	ml/30 min	<100		
5.	Rheology		90°C	Cp, lb/100 sqft	Pv Yp Vc		
6.	Compressive Strength		150°C, Pr. 3000 R/T 24hrs	Psi	After 24 hours After 72 hours	1875	
7.	Stability		120°C	gm/cc	Top Bottom		

<u>Table No. 3</u>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Temperature (°C)
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40
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10
0
Consistency (Bc)
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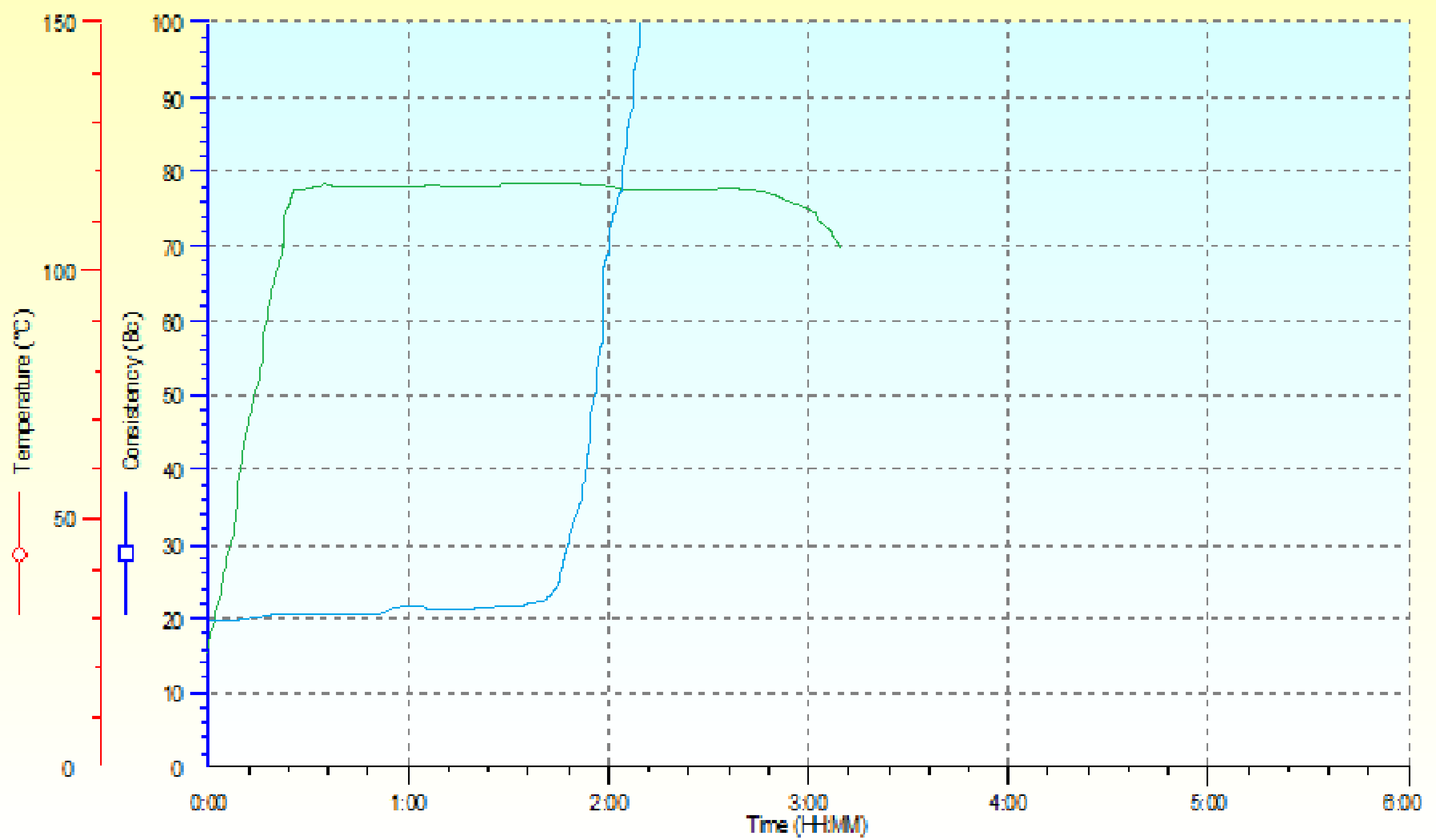
1:30
2:00
2:30
3:00
3:30
Time (HH:MM)

Graph No. 3

Slurry Design Composition 04 for GNSGA well dated 27-02-2015 @ Consistometer No. 05: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + Sio_2 + SF + 100 52 33 8 Kcl + H447 + S.HT (Dry B) + 0 0.8 0.2 CFR-3 + HR-12 + Gas Stop HT + 0 0.5 0.4 nTBP 0.1	Temp -116^oC, Pr- 10,000psi, R/T- 40min, 10min break after 75minutes	Min	30Bc at 220min	129min	Thickening time is less than the requirements. Here we are trying to check the effect on the thickening time if we keep some of additives as zero. As these additives are expensive, hence need to prepare an economical, fulfilling site conditions.
2.	Sp. Gravity		-	gm/cc	1.92	1.92	
3.	Free Fluid		116^oC	%	Nil	Nil	
4.	Fluid Loss		At 90^oC / 1000 psi	ml/30 min	<100	62ml/30 min	
5.	Rheology		90^oC	Cp lb/100 sqft ftps	Pv Yp Vc	113.0 18.71 10.5	
6.	Compressive Strength		150^oC, Pr. 3000 R/T 24hrs	Psi	After 24 hours After 72 hours		
7.	Stability		120^oC	gm/cc	Top Bottom		

Table No. 4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Temperature (°C)
Consistency (Bc)
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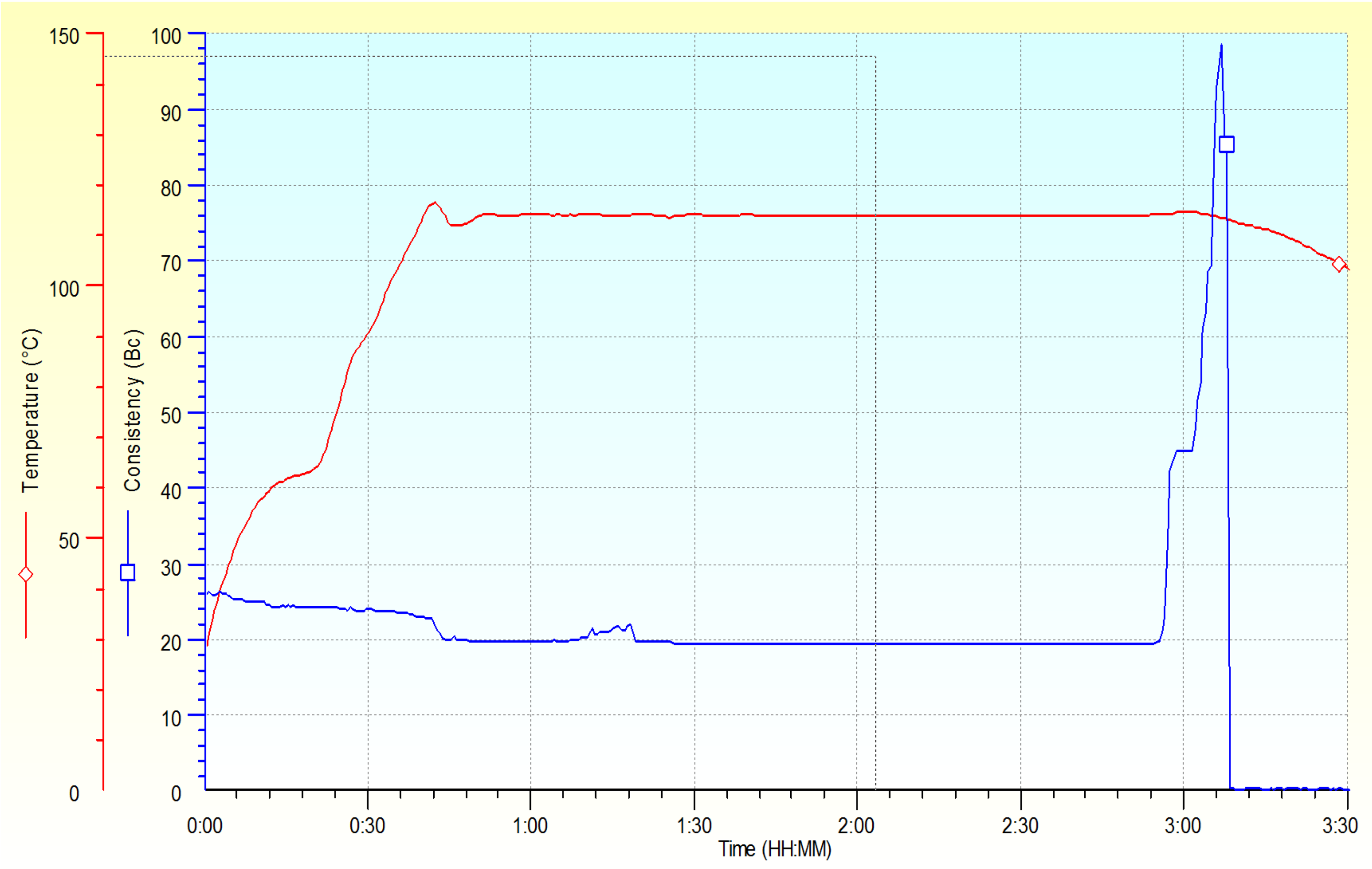
6:00
Time (HH:MM)

Graph No. 4

Slurry Design Composition 05 for GNSGA well dated 02-03-2015 @ Consistometer No. 04: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 52 33 8 Kcl + H447 + S.HT (Dry B) + 0 1 0.2 CFR-3 + HR-12 + Gas Stop HT + 0.2 0.55 0.4 nTBP 0.1	Temp -116^oC, Pr- 10,000psi, R/T- 40min, 10min break after 75minutes	Min	30Bc at 220min	184min	Thickening time is less than the requirements. Need to increase retarder and decrease the accelerator.
2.	Sp. Gravity		-	gm/cc	1.92	1.92	
3.	Free Fluid		116^oC	%	Nil	Nil	
4.	Fluid Loss		At 90^oC / 1000 psi	ml/30 min	<100	24mil/30 min	
5.	Rheology		90^oC	Cp, lb/100 sqft	Pv Yp Vc	161 18 12.6	
6.	Compressive Strength		150^oC, Pr. 3000 R/T 24hrs	Psi	After 24 hours After 72 hours		
7.	Stability		120^oC	gm/cc	Top Bottom		

Table No. 5


150
100
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Temperature (°C)
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90
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60
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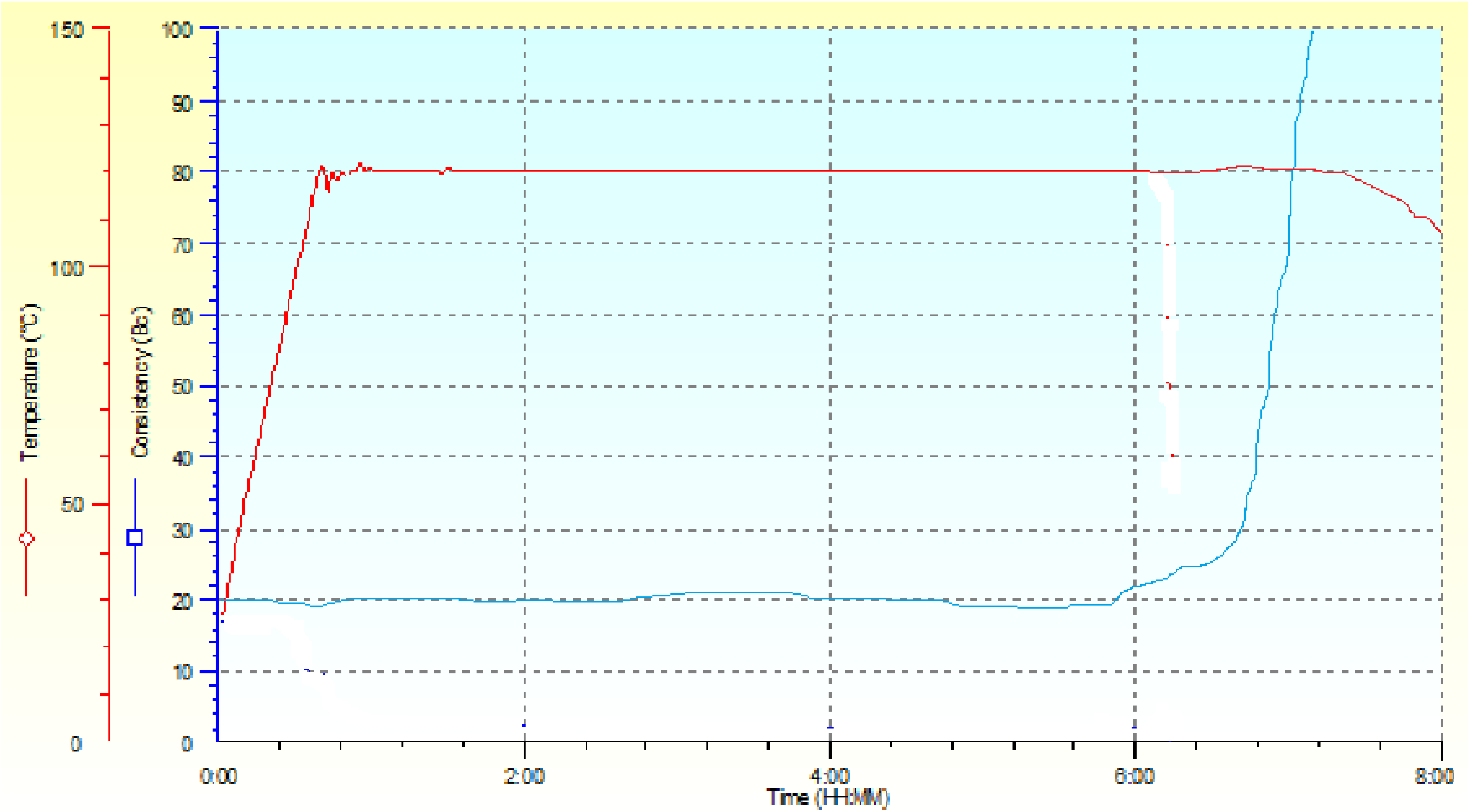
40
30
20
10
0
Consistency (Bc)
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
Time (HH:MM)

Graph No. 5

Slurry Design Composition 06 for GNSGA well dated 11-03-2015 @ Consistometer No. CTEm/c: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 52 33 5 Kcl + H447 + S.HT (Dry B) + 0 1 0.8 CFR-3 + HR-12 + Gas Stop HT + 0 0.55 0.5 nTBP 0.1	Temp -116°C, Pr- 10,000psi, R/T- 40min, 10min break after 75minutes	Min	30Bc at 220min	480min	Initial Consistency =24Bc 30Bc @472min 70Bc @ 475min 100Bc@480min No Hump observed after break of 10 min
2.	Sp. Gravity		-	gm/cc	1.92	1.92	
3.	Free Fluid		116°C	%	Nil	Nil	
4.	Fluid Loss		At 90°C / 1000 psi	ml/30 min	<100	20	
5.	Rheology		90°C	Cp, lb/100 sqft	Pv Yp Vc	124 18.5 11.0	n'=0.717 k'= 0.825
6.	Compressive Strength		150°C, Pr. 3000 R/T 24hrs	Psi	After 24 hours After 72 hours		 2450
7.	Stability		120°C	gm/cc	Top Bottom	1.95 1.95	Stable

Table No. 6


150
100
50
0
Temperature (°C)
Consistency (Bc)
100
90
80
70
60
50
40
30
20
10
0
0:00
2:00
4:00
6:00
8:00
Time (HH:MM)

Graph No. 6

Requisition for well GNSGB, Ankleswar

(A) Well Details and Job Parameters:-

(1) Type of Job : 9-5/8" Cementation.
(2) Depth (meters) : 3150M.
(3) Bit Size / Casing Size : 12-1/4" X 9-5/ 8"Casing.
(4) Cement Rise : 500M
(5) Specific Gravity of Mud : 1.35gm/cc. (Mud Wght=1.26)
(6) Bottom Hole Static Temp (BHST) : 126^{o} C
(7) Bottom Hole Circulating Temp (BHCT) : 88^{o}C.
(8) Specific Gravity of Cement Slurry : 1.90 gm/cc.
(9) Time to reach Temp & Pressure : 60min.
(10) Break in Pumping of Cement Slurry
 i. 1st Break of 10 min after 60min.
 ii. 2nd Break of …. min after ….. Min.
(11) Thickening Time needed : at 30BC, (260Min).
(12) Consistency Data : To be provided.
(13) API Free Water : Nil / Traces.
(14) Fluid Loss : Less than 150ml/30min.
(15) Rheological data:-
 i. P.V. /Y.P. to be provided.
 ii. N' / K' to be provided.
 iii. Critical Velocity (meter /sec).
(16) Compressive Strength : After 24 hours & 72 hours.
(17) Tentative Date of Job :00/00/00.

Remarks:

(B) Details of Samples: -

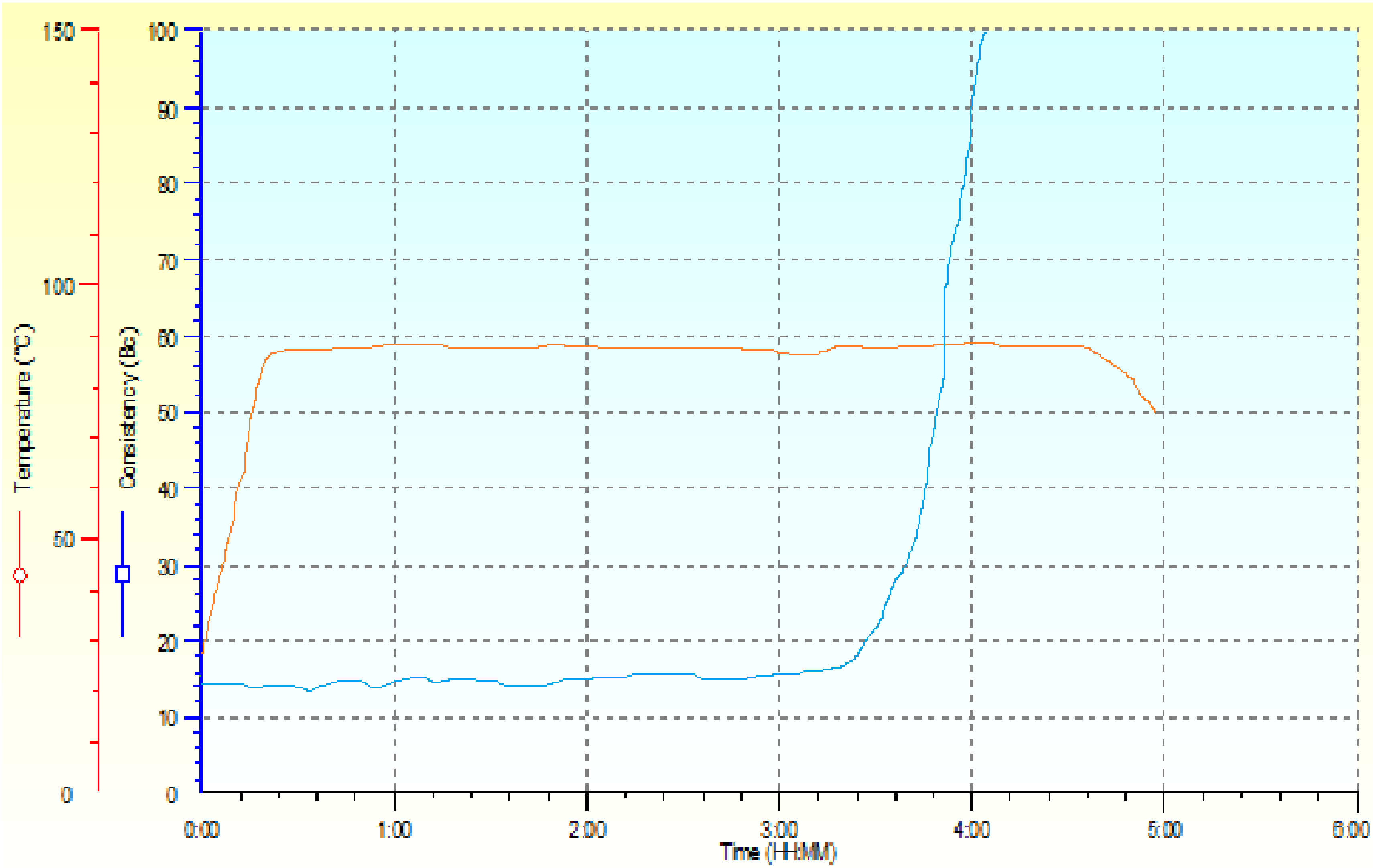
(18) Type of Cement & Lot No. : OWC Digvijay Make Lot-2014
(19) Water : 3GPL water.
(20) Cement Additives to be used for gas tight blended Cement Slurry:
 a. Silica Flour (33% Dry Blended) b. HALAD-447 c. HR-12.
 d. CFR-3. e D-153 f. D-AIR 4000L /. n-TBP

Slurry Design for GNSGB well, Ankleshwar

Slurry Design Composition 01 dated 30-03-2015 Well Name GNSGB @ Consistometer No. 06: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + 100 54 33 H447 + CFR-3 + D-153 + 1.0 0.25 0.4 HR-5 + nTBP 0.20 0.1	Temp -88°C, Pr- 6,000psi, R/T- 40min, 10min break after 60minutes	Min	30Bc at 265min	248min	Initial Bc=14 30Bc@ 220min 70Bc @235min 100Bc@248min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		88°C	%	Nil	Nil	
4.	Fluid Loss		At 88°C / 1000 psi	ml/30 min	<150		
5.	Rheology		88°C	Cp, lb/100 sqft ft/sec	Pv Yp Vc		
6.	Compressive Strength		126°C, Pr. 3000 R/T 240min	Psi	After 24 hours		
7.	Stability		-°C	gm/cc	Top Bottom		Stable

Table No. 7

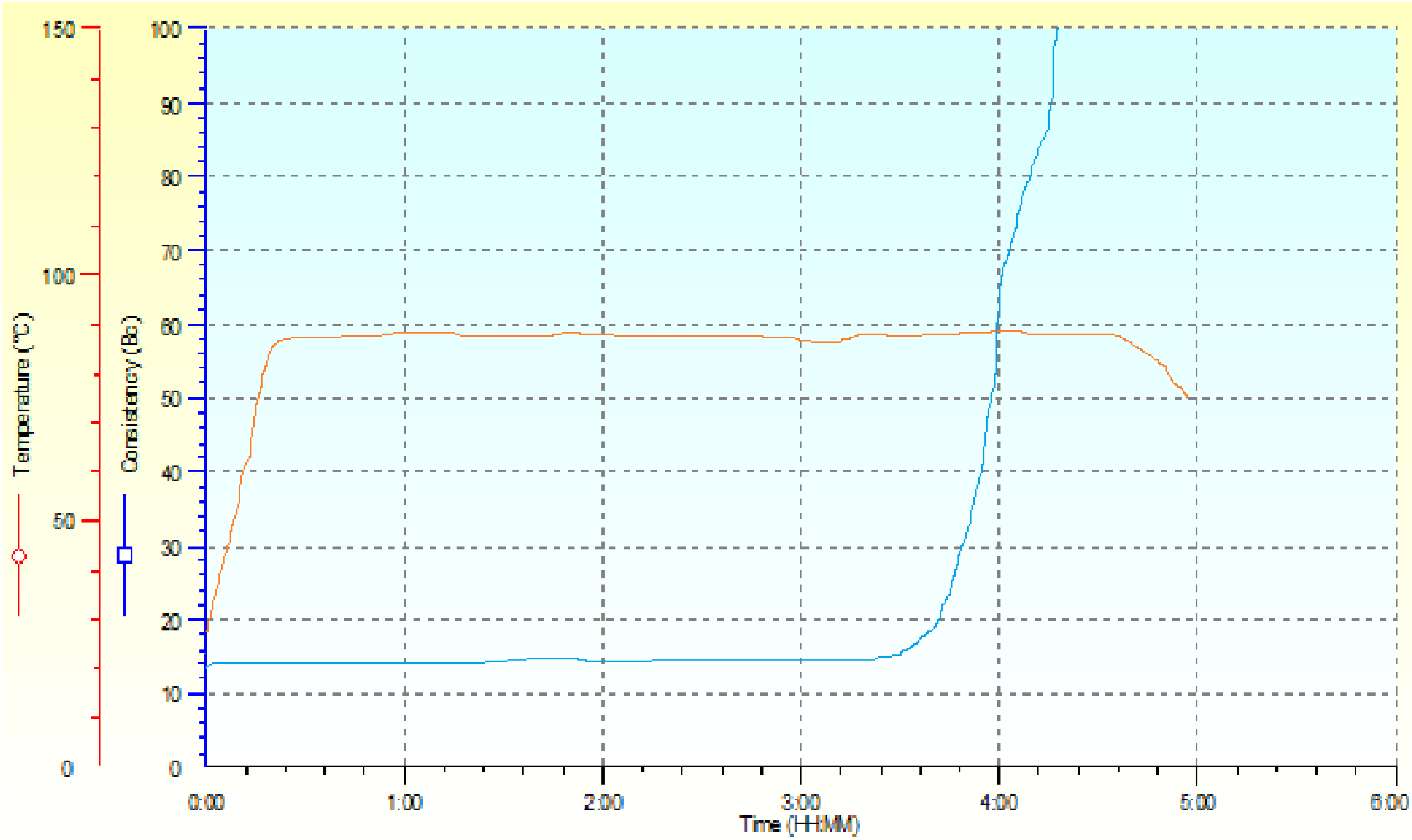

150
100
50
0
Temperature (°C)
100
90
80
70
60
50
40
30
20
10
0
Consistency (Bc)
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph No. 7

Slurry Design Composition 02 dated 04-03-2015 Well Name GNSGB @ Consistometer No. 06: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + 100 54 33 H447 + CFR-3 + D-153 + 1.0 0.10 0.4 HR-5 + nTBP 0.25 0.1	Temp -88^{o}C, Pr- 6,000psi, R/T- 40min, 10min break after 60minutes	Min	30Bc at 265min	260min	Initial Bc=14 30Bc@ 230min 70Bc @245min 100Bc@260min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		88^{o}C	%	Nil	Nil	
4.	Fluid Loss		At 88^{o}C / 1000 psi	ml/30 min	<150		
5.	Rheology		88^{o}C	Cp, lb/100 sqft ft/sec	Pv Yp Vc		
6.	Compressive Strength		126^{o}C, Pr. 3000 R/T 240min	Psi	After 24 hours		
7.	Stability		-^{o}C	gm/cc	Top Bottom		Stable

Table No. 8

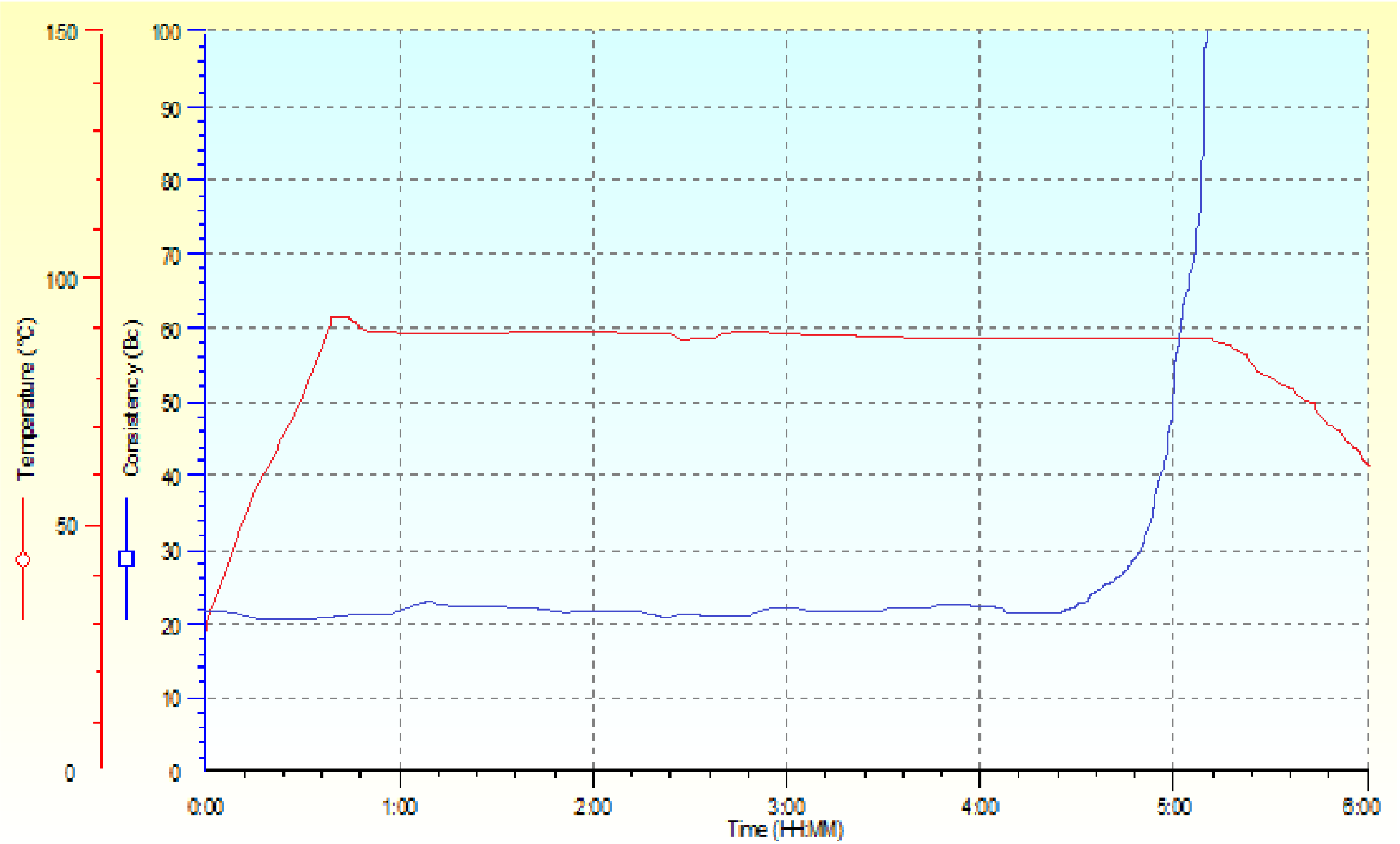

150
100
50
0
Temperature (°C)
Consistency (Bc)
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph no. 8

Slurry Design Composition 02 dated 06-04-2015 Well Name GNSGB @ Consistometer No. 04: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + 100 54 33 H447 + CFR-3 + D-153 + 1.0 0.2 0.4 HR-5 + nTBP 0.25 0.1	Temp -88^oC, Pr- 6,000psi, R/T- 40min, 10min break after 60minutes	Min	30Bc at 265min	310min	Initial Bc=22 30Bc@ 286min 70Bc @301min 100Bc@310min
2.	Sp. Gravity		-	gm/cc	1.90	1.90	
3.	Free Fluid		88^oC	%	Nil	Nil	
4.	Fluid Loss		At 88^oC / 1000 psi	ml/30 min	<150	68	
5.	Rheology		88^oC	Cp, lb/100 sqft ft/sec	Pv Yp Vc	64 22 4.4 (1.4mps)	n'= 0.984 k'= 0.0706 Dail reading 84,65, 42, 34, 28, 21, 18
6.	Compressive Strength		126^oC, Pr. 3000 R/T 240min	Psi	After 24 hours	2140	
7.	Stability		-^oC	gm/cc	Top Bottom		

Table No. 9


150
100
50
0
Temperature (°C)
100
90
80
70
60
50
40
30
20
10
0
Consistency (Bc)
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph No. 9

Requisition for well GNSGC, Ankleswar: -

(A) Well Details and Job Parameters:-

(1) Type of Job : 7” Cementation.
(2) Depth (meters) : 4000M.
(3) Bit Size / Casing Size : 8.1/2” X 7”Casing.
(4) Cement Rise : 650M
(5) Specific Gravity of Mud : 1.45gm/cc.
(6) Bottom Hole Static Temp (BHST) : 153^{o} C
Note: 221.7^{o} F Recorded at 2902m.
(7) Bottom Hole Circulating Temp (BHCT) : 120^{o}C.
(8) Specific Gravity of Cement Slurry : 1.90 gm/cc.
(9) Time to reach Temp & Pressure : 40min.
(10) Break in Pumping of Cement Slurry
 i. 1^{st} Break of 10 min after 45min.
 ii. 2^{nd} Break of 60 min after 150 Min.
(11) Thickening Time needed : at 30BC, (265Min).
(12) Consistency Data : To be provided.
(13) API Free Water : Nil.
(14) Fluid Loss : Less than 50ml/30min.
(15) Rheological data:-
 i. P.V. /Y.P. to be provided.
 ii. N’ / K’ to be provided.
 iii. Critical Velocity (meter /sec).
(16) Compressive Strength : After 24 hours & 72 hours.
(17) Tentative Date of Job :00/00/00.

Remarks:

(B) Details of Samples: -

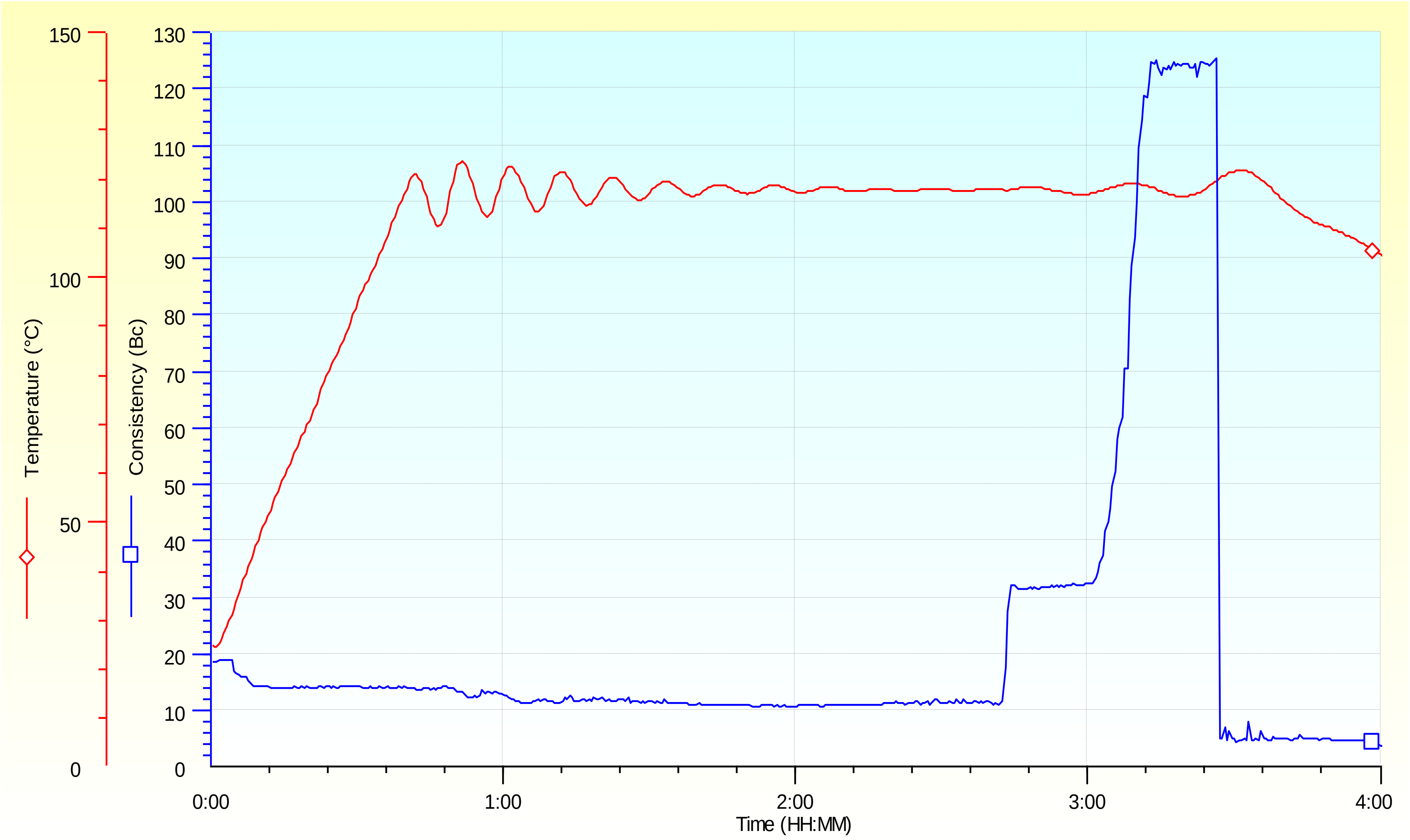
(18) Type of Cement & Lot No. : OWC Digvijay Make Lot-2014
(19) Water : 3GPL water.
(20) Cement Additives to be used for gas tight blended Cement Slurry:
 a. Silica Flour b. Suspend HT (May be dry blended) c. Silica Fume
 d. HALAD-447 e. HR-12. f. Gas Stop HT g. D-AIR 4000L
 h. HALAD 413 i. n-TBP j. CFR-3.

Slurry Design for GNSGC well, Ankleshwar

Slurry Design Composition 01dated 17-03-2015 Well Name GNSGC @ Consistometer No. 04: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 52 33 8 Kcl + H447 + S.HT (Dry B) + 0 1 0.2 CFR-3 + HR-12 + Gas Stop HT + 0.2 0.6 0.4 nTBP 0.1	Temp -120°C, Pr- 9,000psi, R/T- 40min, 10min break after 45minutes	Min	30Bc at 265min	190min	Initial Bc=19 30Bc @165min 70Bc @188min 100Bc@190min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		120°C	%	Nil	Nil	
4.	Fluid Loss		At 90°C / 1000 psi	ml/30 min	<100		
5.	Rheology		90°C	Cp, lb/100 sqft	Pv Yp Vc		
6.	Compressive Strength		153°C, Pr. 3000 R/T 240min	Psi	After 24 hours After 72 hours		
7.	Stability		120°C	gm/cc	Top Bottom		

Table No. 10

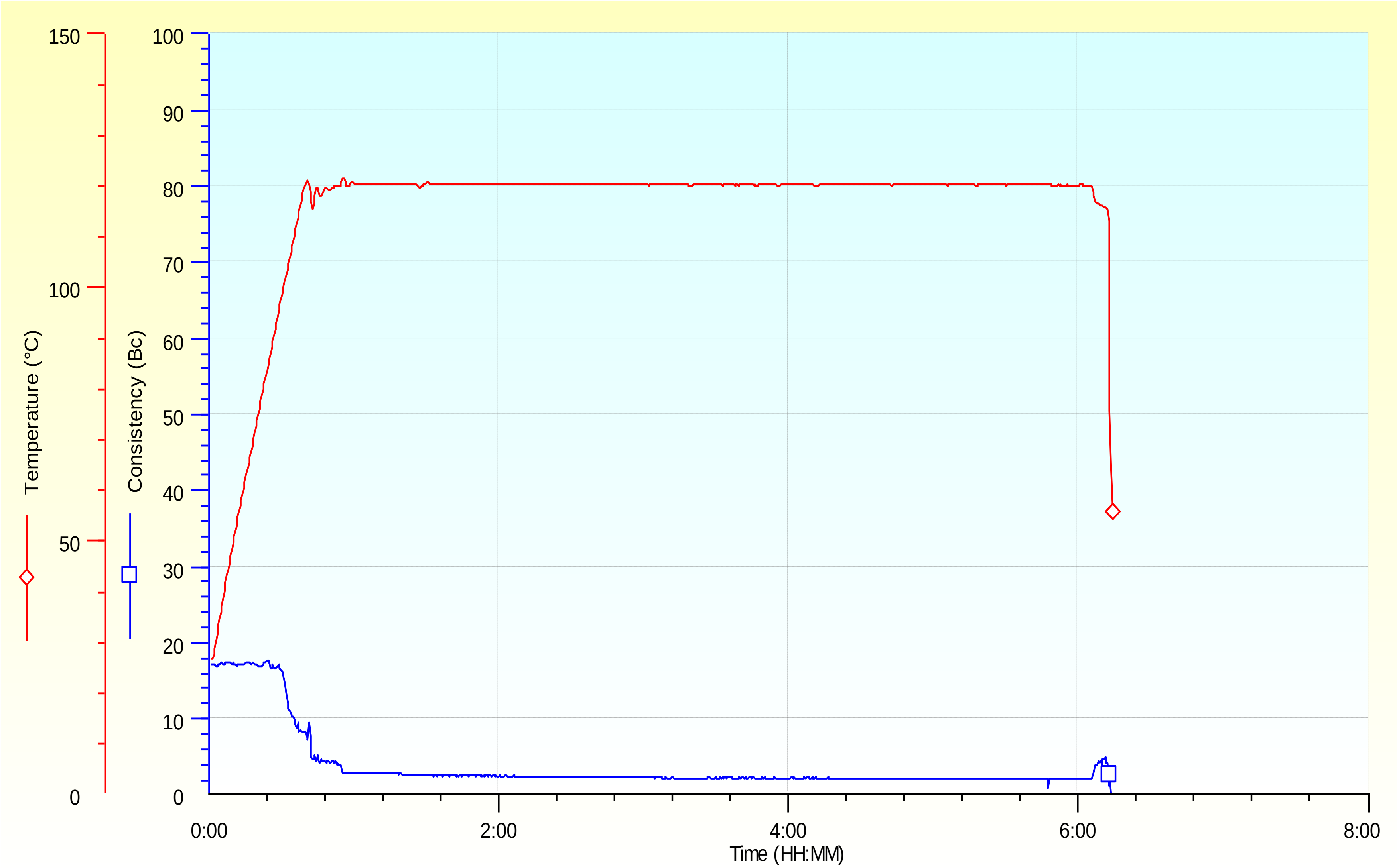

Temperature (°C)
Consistency (Bc)
150
100
50
0
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
2:00
3:00
4:00
Time (HH:MM)

Graph No. 10

Slurry Design Composition 02dated 17-03-2015 Well Name GNSG @ Consistometer No. 04: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + Sio_2 + SF + 100 52 33 8 Kcl + H447 + S.HT (Dry B) + 0 1 0.2 CFR-3 + HR-12 + Gas Stop HT + 0.4 0.7 0.4 nTBP 0.1	Temp -120^oC, Pr- 9,000psi, R/T- 40min, 10min break after 45minutes	Min	30Bc at 265min	340	Slurry didn't Set even after 340 min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		120^oC	%	Nil	Nil	
4.	Fluid Loss		At 90^oC / 1000 psi	ml/30 min	<100	16ml/30 min	
5.	Rheology		90^oC	Cp lb/100 sqft ft/sec	Pv Yp Vc	117 3 8	n' =0.960 k' = 0.150 Dial Reading 120, 84, 45, 28, 16, 5, 3
6.	Compressive Strength		153^oC, Pr. 3000 R/T 240min	Psi	After 24 hours After 72 hours		
7.	Stability		120^oC	gm/cc	Top Bottom		

Table No. 11

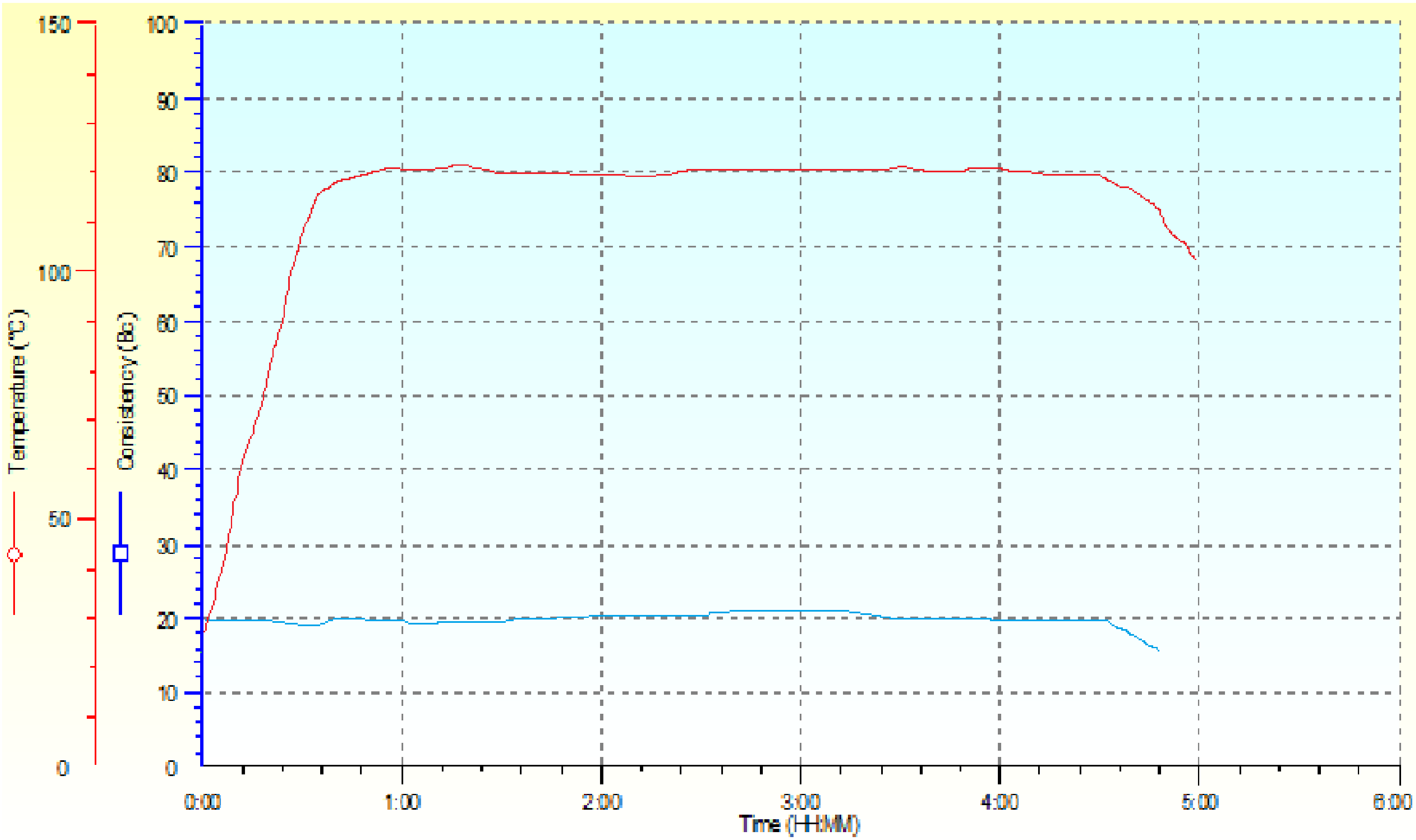

150
100
50
0
Temperature (°C)
100
90
80
70
60
50
40
30
20
10
0
Consistency (Bc)
0:00
2:00
4:00
6:00
8:00
Time (HH:MM)

Graph No. 11

Slurry Design Composition 03dated 18-03-2015 Well Name GNSGC @ Consistometer No. 06: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 46 33 0 Kcl + H447 + S.HT (Dry B) + 0 0.8 0 CFR-3 + HR-12 + Gas Stop HT + 0.2 0.8 0.4 nTBP 0.1	Temp -120°C, Pr- 9,000psi, R/T- 40min, 10min break after 45minutes	Min	30Bc at 265min	280min*	Initial Bc = 20 *Slurry didn't set up to 280 min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		120°C	%	Nil	Nil	
4.	Fluid Loss		At 90°C / 1000 psi	ml/30 min	<100		
5.	Rheology		90°C	Cp, lb/100 sqft ft/sec	Pv Yp Vc		Settling observed
6.	Compressive Strength		153°C, Pr. 3000 R/T 240min	Psi	After 24 hours After 72 hours		
7.	Stability		120°C	gm/cc	Top Bottom		

Table No. 12

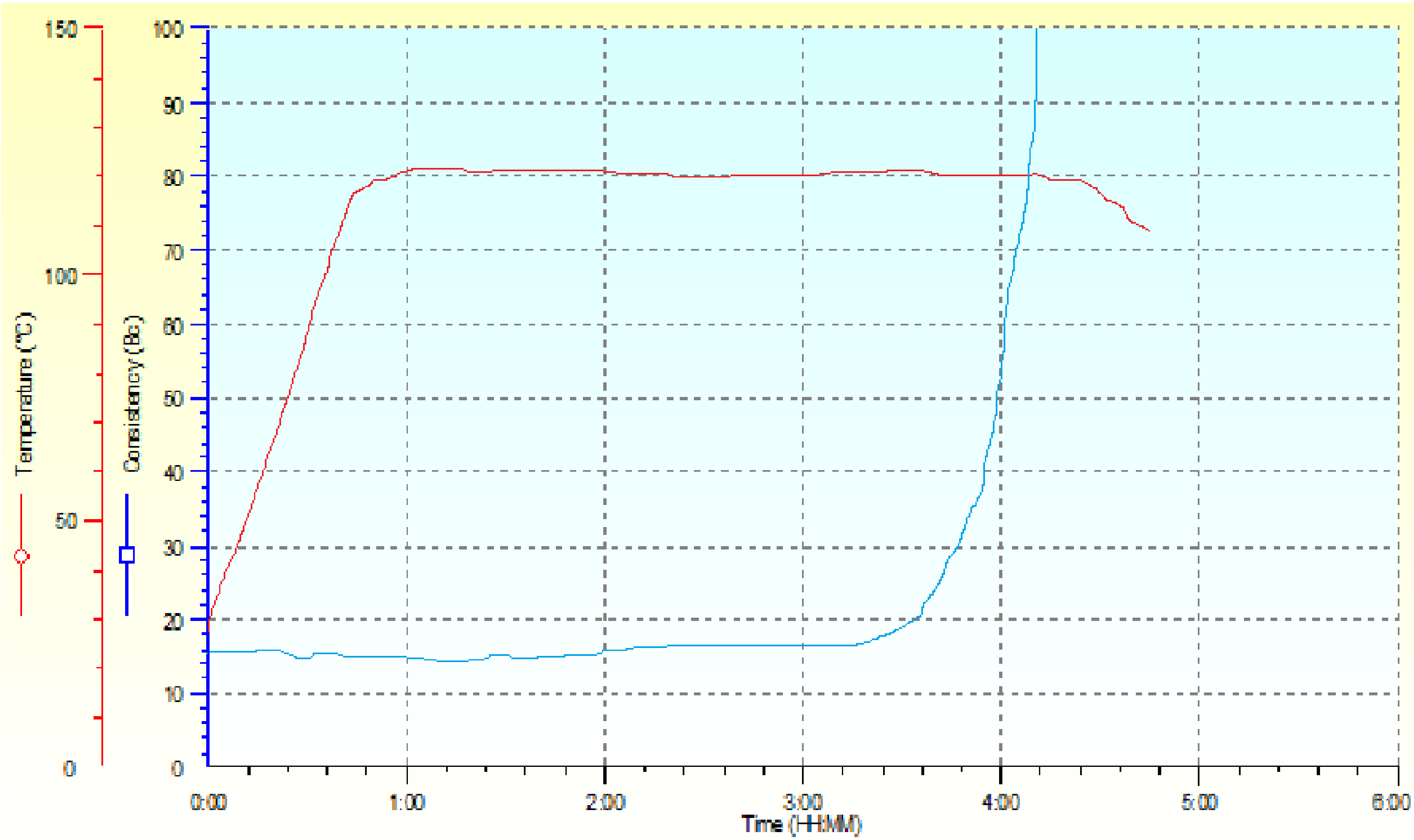

150
100
50
0
Temperature (°C)
Consistency (Bc)
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph No. 12

Slurry Design Composition 04dated 19-03-2015 Well Name GNSG @ Consistometer No. 06: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 46 33 0 Kcl + H447 + S.HT (Dry B) + 0 0.8 0 CFR-3 + HR-12 + Gas Stop HT + 0.4 0.6 0.2 nTBP 0.1	Temp -120°C, Pr- 9,000psi, R/T- 40min, 10min break after 45minutes	Min	30Bc at 265min	253min	Initial Bc=16 30Bc@ 236min 70Bc @246min 100Bc@253min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		120°C	%	Nil	Nil	
4.	Fluid Loss		At 90°C / 1000 psi	ml/30 min	<100		
5.	Rheology		90°C	Cp, lb/100 sqft	Pv Yp Vc		
6.	Compressive Strength		153°C, Pr. 3000 R/T 240min	Psi	After 24 hours After 72 hours		
7.	Stability		120°C	gm/cc	Top Bottom		

Table No. 13

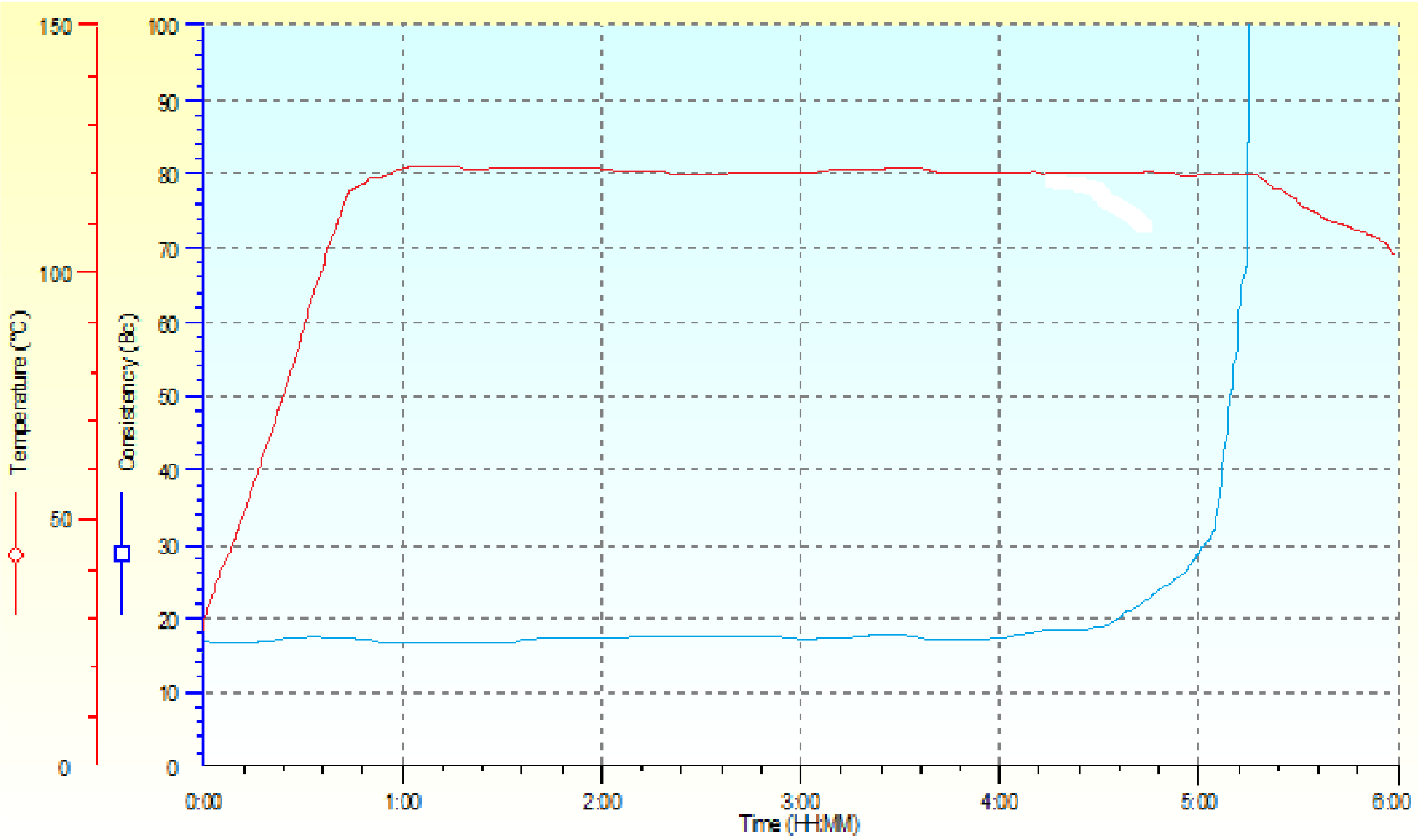

150
100
50
0
Temperature (°C)
Consistency (Bc)
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph No. 13

Slurry Design Composition 05dated 19-03-2015 Well Name GNSG @ Consistometer No. 04: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + Sio_2 + SF + 100 52 33 8 Kcl + H447 + S.HT (Dry B) + 0 1 0.2 CFR-3 + HR-12 + Gas Stop HT + 0 0.65 0.4 nTBP 0.1	Temp -120^{o}C, Pr- 9,000psi, R/T- 40min, 10min break after 45minutes	Min	30Bc at 265min	316min	Initial Bc=17 30Bc@ 301min 70Bc @312min 100Bc@316min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		120^{o}C	%	Nil	Nil	
4.	Fluid Loss		At 88^{o}C / 1000 psi	ml/30 min	<100		
5.	Rheology		88^{o}C	Cp, lb/100 sqft	Pv Yp Vc		
6.	Compressive Strength		153^{o}C, Pr. 3000 R/T 240min	Psi	After 24 hours After 72 hours	2828 3390	
7.	Stability		120^{o}C	gm/cc	Top Bottom	1.911 1.905	Stable

Table No. 14

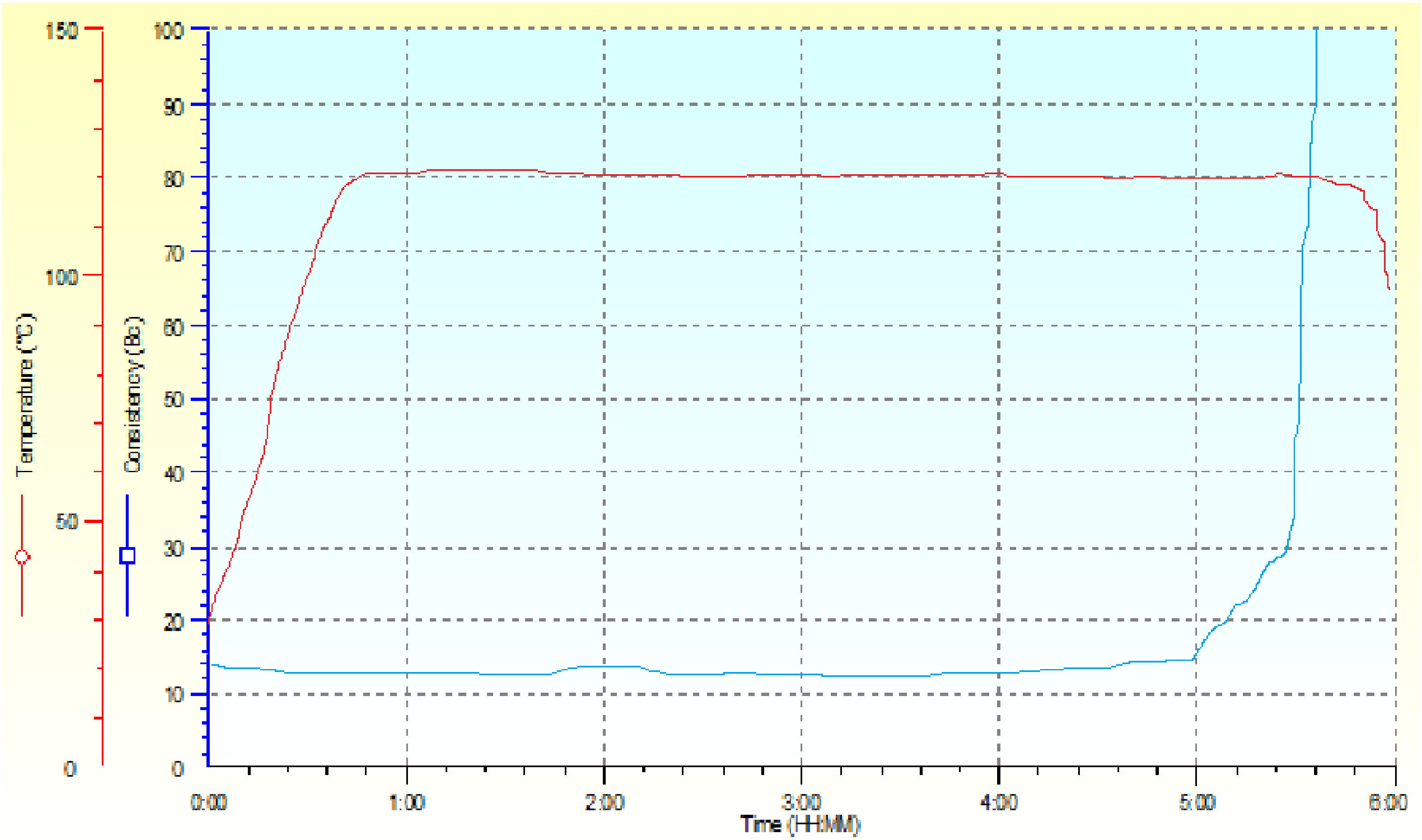

150
100
50
0
Temperature (°C)
100
90
80
70
60
50
40
30
20
10
0
Consistency (Bc)
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph No. 14

Slurry Design Composition 06dated 27-03-2015 Well Name GNSG @ Consistometer No. 06: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 52 33 8 Kcl + H447 + S.HT (Dry B) + 3 0.8 0.2 CFR-3 + HR-12 + Gas Stop HT + 0.5 0.7 0.4 nTBP 0.1	Temp -120^oC, Pr- 9,000psi, R/T- 40min, 10min break after 45minutes	Min	30Bc at 265min	350min	Initial Bc=12 30Bc@ 330min 70Bc @344min 100Bc@350min
2.	Sp. Gravity		-	gm/cc	1.90	1.93	
3.	Free Fluid		120^oC	%	Nil	Nil	
4.	Fluid Loss		At 88^oC / 1000 psi	ml/30 min	<100		
5.	Rheology		88^oC	Cp, lb/100 sqft	Pv Yp Vc		
6.	Compressive Strength		153^oC, Pr. 3000 R/T 240min	Psi	After 24 hours After 72 hours		
7.	Stability		120^oC	gm/cc	Top Bottom		

Table No. 15

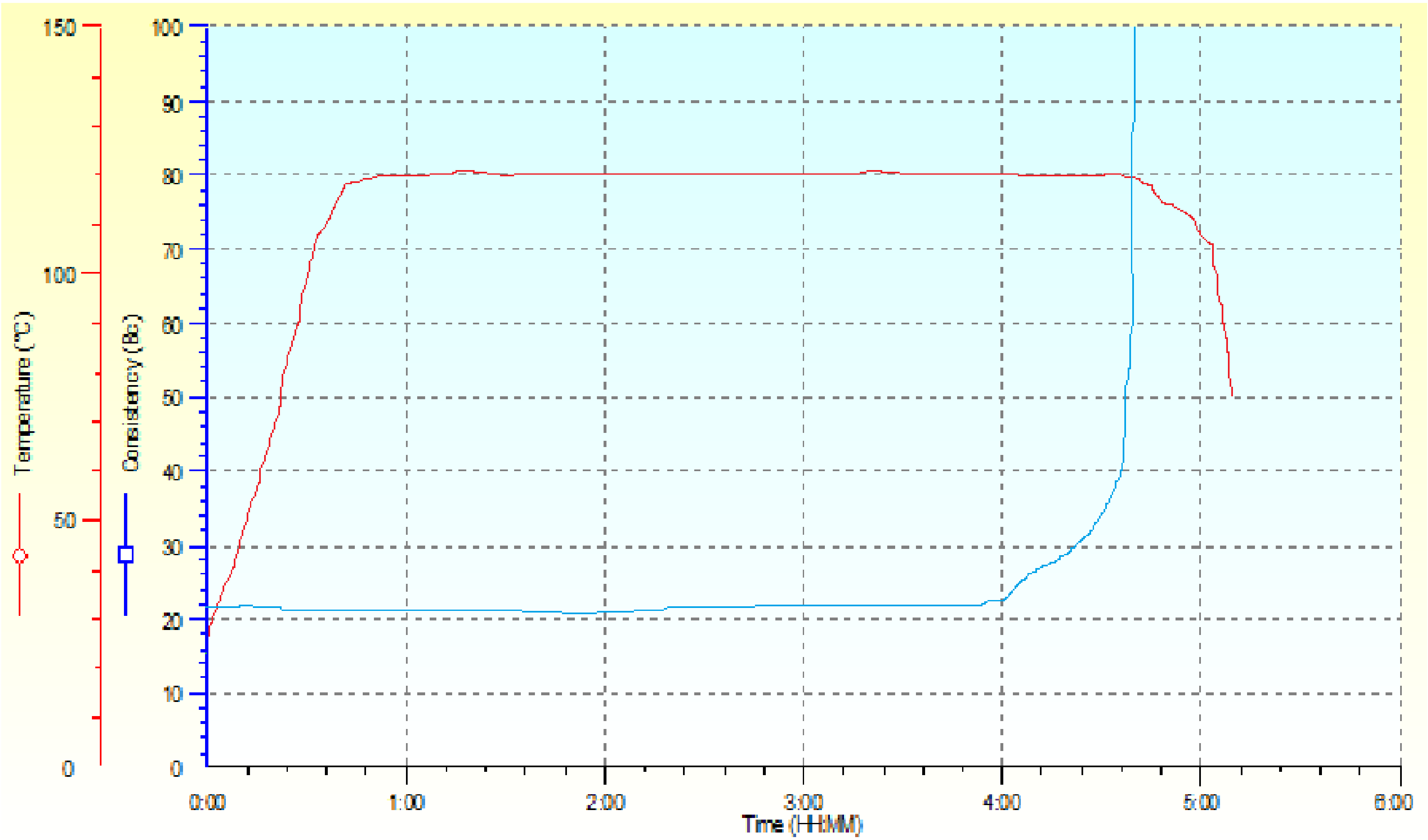

Temperature (°C)
Consistency (Bc)
Time (HH:MM)
150
100
50
0
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00

Graph No. 15

Slurry Design Composition 07dated 31-03-2015 Well Name GNSG @ Consistometer No. 04: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 52 33 8 Kcl + H447 + S.HT (Dry B) + 0 1 0.2 CFR-3 + HR-12 + Gas Stop HT + 0 0.65 0.6 nTBP 0.1	Temp -120^{o}C, Pr- 9,000psi, R/T- 40min, 10min break after 45minutes	Min	30Bc at 265min	280min	Initial Bc=22 30Bc@ 262min 70Bc @272min 100Bc@280min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		120^{o}C	%	Nil	Nil	
4.	Fluid Loss		At 88^{o}C / 1000 psi	ml/30 min	<100		
5.	Rheology		88^{o}C	Cp, lb/100 sqft	Pv Yp Vc		
6.	Compressive Strength		153^{o}C, Pr. 3000 R/T 240min	Psi	After 24 hours After 72 hours		
7.	Stability		120^{o}C	gm/cc	Top Bottom		

Table No. 16

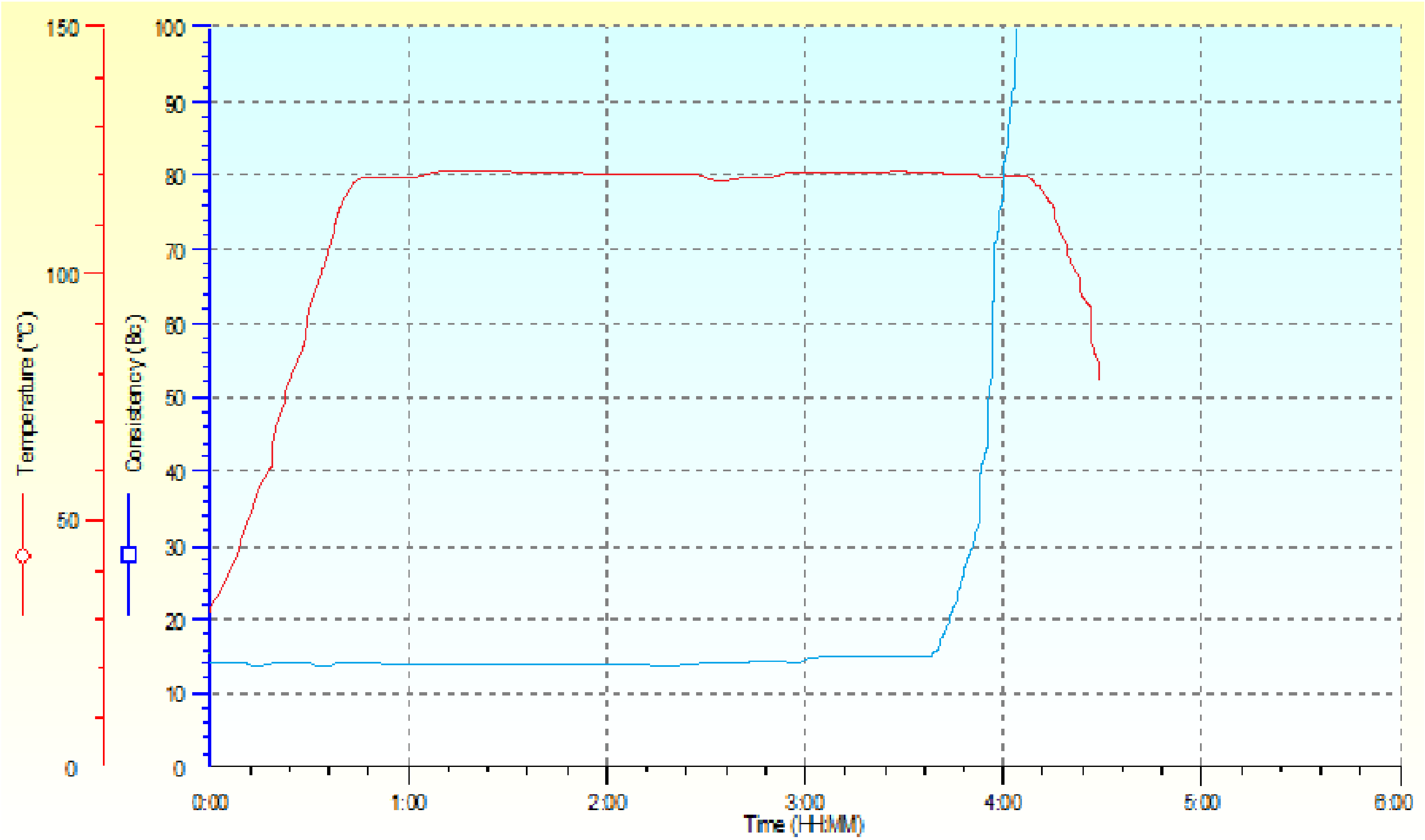

150
100
50
0
Temperature (°C)
Consistency (Bc)
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph no. 16

Slurry Design Composition 08 dated 15-04-2015 Well Name GNSG @ Consistometer No. 04: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + Sio_2 + SF + 100 52 33 8 Kcl + H447 + S.HT (Dry B) + 3 0.8 0.8 CFR-3 + HR-12 + Gas Stop HT + 0 0.4 0.5 nTBP 0.1	Temp -120°C, Pr- 9,000psi, R/T- 40min, 10min break after 45minutes	Min	30Bc at 265min	248min	Initial Bc=14 30Bc@ 220min 70Bc @235min 100Bc@248min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		120°C	%	Nil	Nil	
4.	Fluid Loss		At 88°C / 1000 psi	ml/30 min	<100		
5.	Rheology		88°C	Cp, lb/100 sqft	Pv Yp Vc		
6.	Compressive Strength		153°C, Pr. 3000 R/T 240min	Psi	After 24 hours After 72 hours		
7.	Stability		120°C	gm/cc	Top Bottom		Stable

Table No. 17

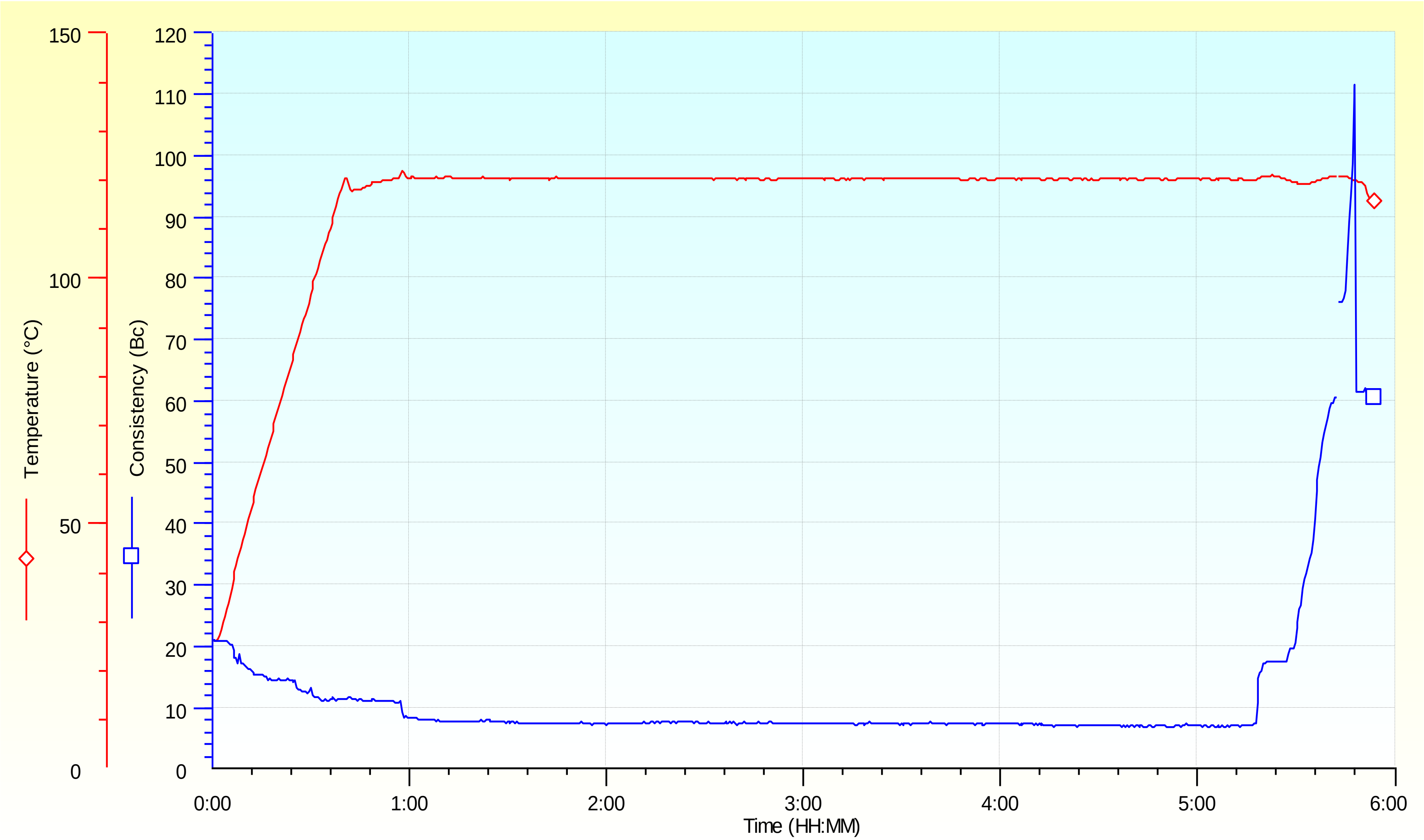

150
100
50
0
Temperature (°C)
Consistency (Bc)
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph No. 17

Slurry Design Composition 08 (Final) dated 16-04-2015 Well Name GNSGC @ Consistometer No. 06: -

S. No.	Parameters	Composition, % BWOC	Conditions	Unit	Design Requirements	Results	Remarks
1.	Thickening Time	Cement + Water + SiO_2 + SF + 100 52 33 8 Kcl + H447 + S.HT (Dry B) + 0 1 0.2 CFR-3 + HR-12 + Gas Stop HT + 0.2 0.55 0.6 nTBP 0.1	Temp -120°C, Pr- 9,000psi, R/T- 40min, 10min break after 45minutes	Min	30Bc at 265min	348min	Initial Bc=20 30Bc@ 336min 70Bc @342min 100Bc@348min
2.	Sp. Gravity		-	gm/cc	1.90	1.92	
3.	Free Fluid		120°C	%	Nil	Nil	
4.	Fluid Loss		At 90°C / 1000 psi	ml/30 min	<100	16ml/30 min	
5.	Rheology		90°C	Cp lb/100 sqft ft/sec	Pv Yp Vc	98 14 9	n' =0.976 k'= 0.489 Dial reading 110,75, 43, 28, 17, 5, 3
6.	Compressive Strength		153°C, Pr. 3000 R/T 240min	Psi	After 24 hours After 72 hours	2828 3390	
7.	Stability		120°C	gm/cc	Top Bottom	1.905 1.911	Stable

Table No 18


150
100
50
0
120
110
100
90
80
70
60
50
40
30
20
10
0
Temperature (°C)
Consistency (Bc)
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Time (HH:MM)

Graph No. 18

CONCLUSION: -

Based on the studies performed & results obtained the following conclusion can be firmed up: -

- The cement slurry was designed for well GNSGA, GNSGB & GNSGC with gas tight behaviors, right angle setting and all the parameters like fluid loss < 50ml /30min, free water nil compressive strength, rheology are found within described limit .

Cement slurry was also designed with 3% KCl as expensive slurry to avoid the swelling of shale and also obtained all desired parameters required for good cementation.

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