Introduction

It is well kwon in oil and gas industry that Carbon dioxide has corrosive effects on well cement integrity when exposed for long time. Along with the increasing pressure on environmental concerns, one component of the program to reduce CO2 in the atmosphere is to inject it into deep aquifers where it will remain for centuries or longer. The Carbon Mitigation Initiative at Princeton University addresses many aspects of the greenhouse gas problem, ranging from climate modeling, to the economics and technology for carbon capture, to injection and storage. Our piece of the problem is to study the mechanisms by which CO2 could escape through abandoned oil wells that penetrate the zone in which the gas is stored. In work initiated by Andrew Duguid [1] and extended by Ed Matteo. A model for the reactive transport process has been developed primarily by Bruno Huet and Prof. Jean Prévost [2] that provides accurate predictions of the rate of attack.

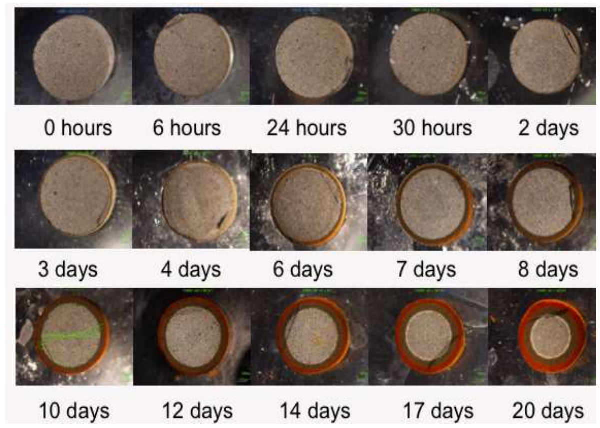
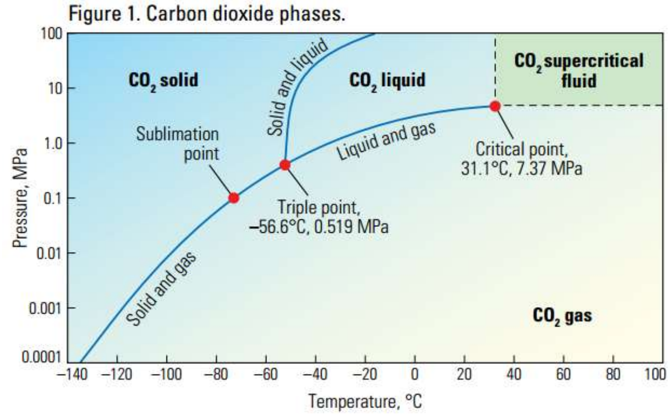


Figure 1. Carbon dioxide phases.



When CO_2 is stored underground, when contacted with formation water, it has potential to become corrosive to set cement, compromising the integrity of the well. Figure 1 show all three phases – Solid, Liquid and Gaseous CO_2 at different pressure and temperature[3]. Therefore, for CO_2 existence well or storage well, it is crucially important to engineer the cement system to sustain the hostile environment of differential loading and temperatures changes. The pressure and temperature changes can be caused by injection, completion, shut in, stimulation pumping and etc.

OPT has created a set of cement system that is capable of tackling various technical challenges:

CO_2 or H_2S Resistance

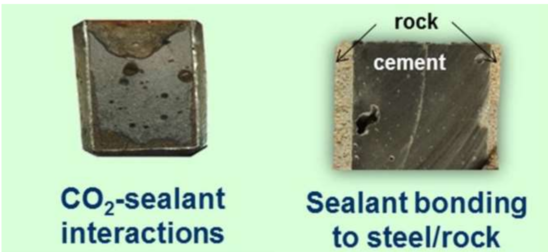
CORCem - Corrosion Resistant Cement. OPT uses particle size distribution PETCem™ to design this type of cement slurry. By reducing the water contents, the cement slurry will have less permeability and developed excellence set cement property early. Additive used is KCM027 - An OPT proprietary product. It is an inorganic powder that can be added into regular Portland cement systems to improve both cement strength and chemical resistance to corrosive environment such as CO_2 and H_2S bearing formations. It not only reduces cement permeability to prevent the encroachment of corrosive fluids, but also reacts with extra lime in cement to improve the compressive strength of the cement. By reducing the lime contains, the

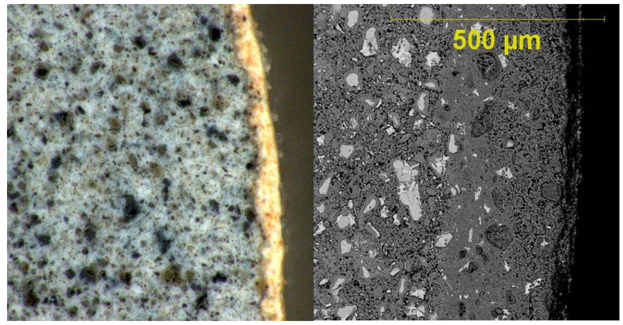
[1] "Degradation of Oilwell Cement Due to Exposure to Carbonated Brine", Andrew Duguid, George W. Scherer, Int. J. Greenhouse Gas Control, 4 (2010) 546–560

[2] "Carbonation of Wellbore Cement by CO2 Diffusion from Caprock", G.W. Scherer and B. Huet, Int. J. Greenhouse Gas Control, 3 (2009) 731–735

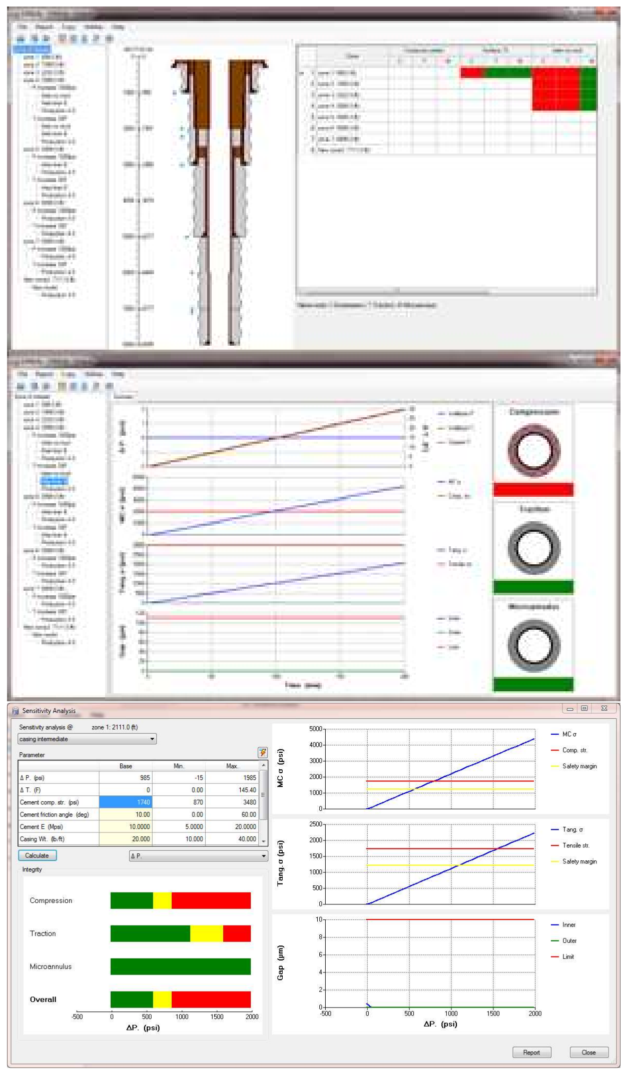
[3] Oilfield Review magazines Issue 27, September 2015

chances of acidic CO_2 condensate to react with set cement is lesser[4]. Depending on the temperature, mixing water and density, up to 3-15% BWOC is generally required to have effective corrosion control and strength improvement. Theoretically KCM027 can be used at any applicable cementing temperatures and densities due to its chemical and physical natures. It contains more than 90% of Metal Oxide.





Once reacted with the lime in the cement during hydration process, the final product is a sealant system which prohibit the further penetration of the Gaseous CO_2 to get in contact with the Portland cement. Once provide long term resistance to CO_2 attack



Enhance Mechanical Property

Typically, CO_2 storage wells are exposed to huge differential pressure and wide temperature range. During injection, pressure is high; during shut in, pressure reduced. Depending on the downhole temperature, the gas temperature is different during injection and shut in.

To analyze the wellbore stress, OPT uses the CEMLife - Cement Stress by Pegasus Vertex Inc. This software analyzes three (3) types of cement failures modes (Traction, compression, micro-annulus) under a set of various temperature conditions and pressures changes. CEMLife performs calculation on the impact of 8 different parameters to quickly achieve the slurry optimization with its sensitivity analysis feature. The analysis has the following features:

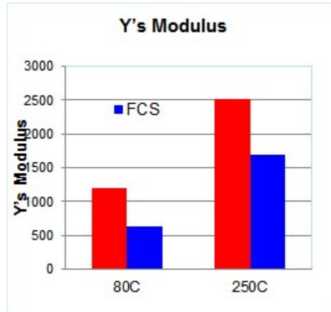
- Whole wellbore analysis (multiple zones)
- Multiple casing strings
- Different cement properties in each cement column
- Sensitivity Analysis for risk management

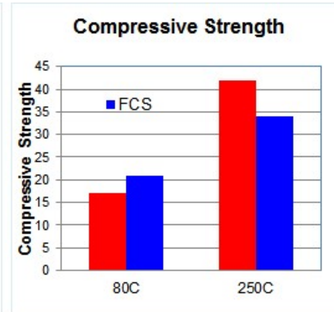
[4] "Experimental Study of the Diffusion-Controlled Acid Degradation of Class H Portland Cement", E.N. Matteo and G.W. Scherer, Int. J. Greenhouse Gas Control (2011),

- Load changing and failure animations.

More information can be found in http://www.pvisoftware.com/cemlife-cement-stress.html

Once a well stress analysis is done, a stress profile and required set mechanical property is known, OPT design the FCS™- Flexible Cement System to accommodate the range of Young Modulus and Poison Ratio allowed before the cement fails. OPT uses the product KCM024, a proprietary product. The mechanical properties of set cement are determined by KCM024 concentrations in terms of Young's Modulus. Higher concentration of KCM024 results in lower Young's Modulus value and lower compressive strength. In combine with Particle Engineering Technology (PETCem™), the cement system can be designed to exhibit excellent set properties to meet the well requirement. It has been tested that the Young Modulus can be 30% lower than typical neat G cement even at high temperature as much as 250°C.





KCM024 is flexible polymer material to modify the mechanical properties of set cement, it was developed specifically for gas well, HTHP wells, steam injection wells and wells drilled in tectonically active areas.

PETCem™

This technology is normally used when slurry density less than 1.5SG (PETCem™ LD) or greater than 2.0 SG (PETCem™ HD) is required in cementing design.

Slurry properties are difficult to maintain under extreme conditions which requires ultra-low or ultra-high densities. In slurry design with PETCem™ technology, pumpable and stable slurry is still maintained at high density up to 2.6 SG, and rapid compressive strength development can also be obtained at very low density of up to 1.2 SG. Therefore PETCem™ technology extends application ranges of traditional cement systems to much higher levels.

There are typically eight products in PETCem Technology.

>> There are high density particles KCM019,

>> Medium density particles KCM020,

>> LP Low density particles KCM021,

>> Multifunctional extender KCM029,

>> Low density particles KCM030, and

>> Light weight extender KCM033.

OPT

Micro-Annulus Prevention

Micro-Annulus is a small gap that can form between the casing or liner and the surrounding cement sheath, most commonly formed by variations in temperature or pressure during or after the cementing process. Such variations cause small movement of the steel casing, breaking the cement bond and creating a micro-annulus that is typically partial.

In order to solve the problem, it has been proven that using a Flexible, Expandable Sealant System to Prevent Micro annulus in a Gas Well [5]. OPT uses KCM025, an OPT proprietary product. KCM025 is a solid cement additives which contains combination of several metal oxides, which provides cement expansion after setting, tighten cement against the casing and the formation by exerting the compressive forces against both surfaces. This sealing effect prevents and reduces micro-annulus and fluids migration, and improves the primary cementing results. The application temperature ranges of KCM025 is between 27°C and 204°C, the degree of expansion is strongly affected by the temperature and cement system design. For the conventional cement slurry system with density of 1.89kg/cm3, typical concentration range is between 1% and 5%BWOC.

Holistic Well Integrity Solution

Technical Features	CEMLife*	Corrosion Resistent Cement CORCem	Flexible Cement System FCS™	Particle Engineered PETCem™	Expandable Cement
Borehole Stress Analysis	√				√
Pressure & Temperature Sensitivity	√	√	√	√	√
CO_2 Resistant		√		√	
H_2S Resistent		√		√	
Elastic Property	√		√	√	
High Compressive Stregth	√			√	
Microannulus Prevention				√	√

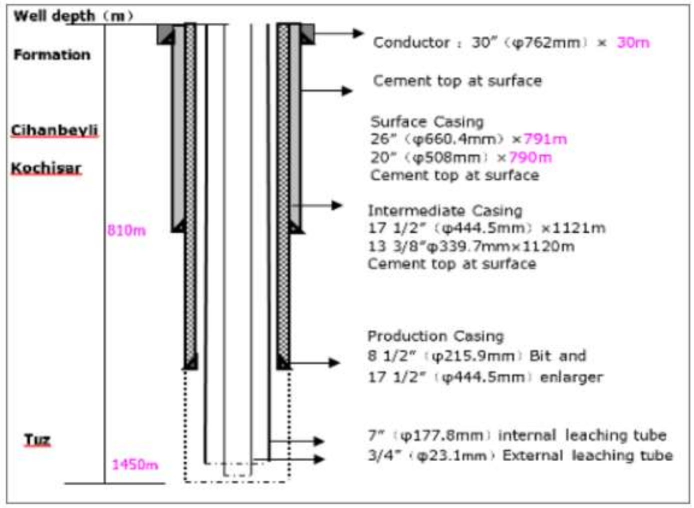
* CEMLife is mark of Pegasus Vertex Inc

[5] SPE-92361-MS Using a Flexible, Expandable Sealant System to Prevent Micro-annulus in a Gas Well: A Case History

Turkey Underground Gas Storage CO_2 Resistant Cement Case Study

Background / Overview

The development objective of the Tuz Gölü Underground Natural Gas Storage Project which is located in Sultanhanı locality of Aksaray province, at about 40 km south of Tuz Gölü, aims to answer the increased energy demand by storing and using natural gas underground, about 200 kilometers south of Ankara, south bank of TUZ GULU lake. The project aims to build a 1.5 billion cubic underground natural gas storage, Design for 12 wells, it is Turkish's government strategic resource reserve project and nation's key project. OPT was working under master EPC project contract holder China Tianchen engineering.



Challenges

The project of high cementing quality 20" (508mm) casing cementing requires good double interface cementing integrity, 13-3/8"(339.7mm) casing cementing requires single interface cement integrity, the second interface requires minimum 60% of good bonding. All well expected to pass pressure integrity test of less than 0.5 Mpa pressure drop within 72 hours. Due to low pressure gradient and salt layers, cementing process requires the use of low temperature and low density, high strength flexible cementing slurry system.

Challenges

The differential pressure expected during injection and shut in was 5000 psi. The CO_2 content was up to 8%. The temperature different between injection and shut in is around 20C.

Test item	Test condition	Actual performance
Density g/cm^3	API Specification	lead cement slurry 1.70
		tail cement slurry 2.0
Filter loss mL/30min	6.9MPa/BHCT	25~30
Static temperature		45
Thickening time min	API Specification	operating time +60min
Free fluid volume mL	2h/BHST	0
Initial consistency Bc	API Specification	14~18
Transient time min	API Specification	12
Concrete stone stability g/cm^3	API Specification	0.005
Burst resistance of lead cement slurry MPa/72h	API Specification	26.5
Burst resistance of tail cement slurry MPa/72h	API Specification	37.2

OPT use the KCM027, KCM025 and KCM024 to formulate the cement slurry for 13-3/8" Casing. Using PETCem engineering, cement blend is done with particle size distribution in order to get the proper slutty rheology and solid contents.

(Refer to example slurry design attached)

Results

As of May 31, 2014, total of 7 wells were successfully completed (UGS - 8, UGS - 7, UGS - 6, UGS - 9, UGS - 2, UGS (repair), UGS - 4-5). The cementing quality meet all the design requirements, including four Wells completed gas seal test, qualified to complete the well and start dissolving cavity. Especially UGS - 9 Wells, the 13-3/8" (339.7 mm) casing cementing quality merit factor 100% good bonding, the second interface cementing bond quality 100%, with 86% achieve below 5mV reading, the best result among all other wells.

(Refer to service ticket from our main contractor Tianchen and reference letter)+

H_2S Resistant Cement Case Study: China's Chuandongbei Gas Project

Background / Overview

The Chuandongbei (CDB) Gas project is one the largest onshore gas projects developed in cooperation between Chevron under Unocal East China Sea, Ltd.(49%) AND a Chinese National Oil company Petrochina (51%). Covering an area of over 800 square kilometers in Sichuan province and Chongqing municipality in southwest China, the project is estimated to contain total potentially recoverable natural gas resources of 3 trillion cubic feet. The CDB Project is significant to southwest China as it brings reliable, affordable and clean energy in the region[6]. A long with this, many other concessions were held by 100% ownership of Petrochina & Sinopec. Such as TieShanPo, DuHeKou and PuGuang block.

Challenges

The CDB Project is built on strong cooperation between Chevron, CNPC and all levels of the Chinese government. The project exhibit huge technical challenges due to its high contains of H_2S and CO_2 contents. A catastrophic occurred with 191 villages and crew was killed due to H_2S and CO_2 poisoning, when the well LuoJia 16-H happen on 25th Dec 2003. Average H2S content distribution the area are:

Are in Chinese Name	Area	H2S Content	CO2 Content
渡河口	Du He Kou	16%	3%
铁山坡	Tie Shan Po	14%	4%
罗家寨	Luo Jia Zai	12%	6%
普光	Pu Guang	16%	2%

Source : China Geoscience 2005,35(11):1037-1046 page

The challenges on this area were very obvious, high contents of Corrosive gas. The formation also contains lots of faults that required lower cement slurry density to bring the top of cement high enough to ensure proper zonal isolation.

Solutions

OPT used Corrosion Resistant material KCM027, couple with flexible cement material KCM024 and KCM025 expanding agent to meet the challenges.

(Refer to attached contract for more details)

6 Chevron Chuandongbei Gas Project Fact Sheet. www.chevronchina.com/.../Chuandongbei%20Gas%20Project%20Fact%20Sheet.pdf