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Cement design for underground gas storage well completion

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ABSTRACT

In order to shave the peak demands during the cold seasons, underground gas storage (UGS), balancing the supply-demand chain throughout the year, has been accepted as a strategic method. During the successive UGS cycles, the well cement experiences cyclic mechanical, thermal, and hydraulic stress and may crack due to its low elasticity and ductility. This could lead to the transmission of stored gas through cementing behind casing, one of the major challenges experienced in UGS operations, so posing high workover costs on UGS wells. In addition to workover costs, the loss of inventory due to gas transmission makes the reservoir insufficient in proper gas supply during the high-demand season. In this work, a new formulation has been invented in order to prevent cement cracking, improve cement elasticity and ductility, and reduce the crack propagation in the cement used for completion of UGS well. The new formulation adds a polymer and an elastomer to cement composition. Results showed that addition of latex to cement decreases the density, hydration and fluid loss of cement; also, the rate of cement bonding decreases. On the other hand, addition of polypropylene fibers results in dramatic improvement of compressive strength and stress strain properties of the cement. In comparison with elastomer, this additive provides a higher threshold elasticity of cement. Also, the combined cohesive effect of latex and flexibility of microfibers brings about the best resistance against excessive pressures.

1. Introduction

Increasing need for sustainable and permanent supply of energy resources, especially natural gas, has led countries to seek for storage facilities. By storage of excess gas supply during low-consumption seasons and shaving the peak demand during high-consumption seasons, underground gas storage (UGS) has been adopted as a strategic method; hence, balancing the supply-demand throughout the year. Verification of the gas inventory, stored during injection phase of a cycle, can assure the operator that gas withdrawal rate will meet the high-season demand. During UGS operations, gas loss, i.e. gas transmission from storage reservoir, is one of the common problems and has been addressed by several researchers, of which the works of Carter and Slagle in 1970, aiming at preventing leakage of gas through a cemented annulus, representing that a potential problem exists. In order to achieve well completion, important factors such as fluid column density and filtration control, as well as such ordinary considerations as pipe movement and centralization, must be carefully taken into account (Carter and Slagle, 1970). In the following, other researchers' works will be discussed. The gas, either through the space behind casings or through reservoir boundaries, may be lost due to transmission out of reservoir. The gas loss through wellbore and behind the casing may occur as a result of drilling fluid density, mud removal, cement slurry, cement hydration and quality of cement between casing and formation. The bonded cement has a very low permeability, so that gas can hardly flow through it. However, cyclic injection/withdrawal (I/W) of gas during successive UGS operation can weaken the cement bond and increase the risk of losing gas inventory within the reservoir. The gas loss was first observed in UGS wells in 1960 (Nelson, 1990). Stone and Christian (1974) studied and modeled the gas transmission through annulus into liquid, gel, and completely bonded cement.

When the cement is characterized by low density and high water-to-cement ratio, its permeability increases by 0.5–5 md (Nelson, 1990), and may let the gas flow. The flow and accumulation of gas into cement may occur slowly, so that the gas leakage, through pressure increase in the annulus, will be traced during weeks or even months afterward. The gas may also transmit out of

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cement by flowing through cement-casing and/or cement-formation interface. Gas loss rate is one of the criteria to evaluate the cement bond after a cement job. Bearden and Lane (1961) proposed an experimental methodology to obtain waiting-on-cement, referred to the time when drilling and completion operations are suspended so that the well's cement can harden sufficiently and determine the mechanical strength of cement bonding against steel. They found that this bonding strength is independent of sample size. Also, there is a relationship between shear and tensile strength of the cement/casing interface. This relationship is a function of cement composition, bonding temperature, pressure, physical properties of casing surface, and bonding time. The shear strength decreases considerably if the casing is mud-wet. Carter and Evans (1964) invented an instrument to direct measure of hydraulic bond strength of cement-casing and cement-formation. They found that, increasing surface smoothness, resulted from mud removal and oil-wet surface, reduces both properties. Becker and Peterson (1963), conducting studies on the shear stress and tensile resistance, found that the cement shear bond strength in the interface between casing and formation depends on wetting properties of surfaces and degree of cement hydration. Parcevaux and Sault (1984) carried out a combined investigation on the shear and hydraulic bond strengths to pipe, total chemical cement contraction, and cement stress/strain relationships. They characterized the nature of the bond by measuring the shear bond stress and the interfacial permeability, and showed that lower chemical contraction and higher cement deformability promote better bonding.

In general, previous studies have shown that there are defects in the cement that have the potential to cause the loss of bond between cement-casing and cement-formation, and increase the risk of gas transmission through the space behind casing. These defects include casing and formation lack in surface roughness, cement volume shrinkage (Gotsis et al., 1984), thin mud layer or mud channels presence at the contact surface (Carter and Evans, 1964; Carter et al., 1973), free water channel or layering in the deviated wells (Tinsley et al., 1979), and excessive thermal, hydraulic, and mechanical stresses at the wellbore (Cain et al., 1965; Matthews and Copeland, 1986).

Recently, addition of new materials to cement composition has been studied to improve properties such as cement tensile stress, water content, etc. It is important for the gas storage wells to keep their cement integrity by means of successive cycles of stress. Cavanagh et al. (2007) invented self-healing cements, in which an especial cement formulation, based on a process called encapsulation, modifies and repairs the cracks (Le Roy-Delage et al., 2010). The Capsules containing restorative materials are present in the cement and break once the cement experiences stresses and cracks propagate inside the cement. The reactive materials released from capsules react with the fluid that encroaches from crack channels into cement. Ravi et al. (2007) measured the cyclic stress of self-healing cements in two successive cycles to study the mechanical properties as well as integrity of cement when put under cyclic loads. They pointed out that laboratory experiments can determine the effect of cyclic loading on the endurance limit of cement, while engineering analysis is required to set the safety factor in cement design. Reddy et al. (2010) examined the performance of healing capsules on healing the cracked cement in different fluid systems, including formation water, oil, and gas. They concluded that the self-healing process is dependent on the type of fluid encroachment into cracks. Cavanagh et al. (2007) tested the performance of self-healing cements in a number of UGS wells. They measured the shut-in casing pressure as an indicator of behind –the-case gas transmission in cement, and concluded that application of these materials reduces the transmission of gas surrounding the well bore.

In Iran, underground Gas storage Company is a subsidiary of National Iranian Gas Company. Natural Gas Storage Company was established in 2007. One of the suitable reservoir for UGS is the Sarajeh reservoir that is depleted hydrocarbon reservoirs. Sarajeh reservoir is a gas/condensate reservoir which is located at 40 km east of Qom city. According to the earlier first stage studies, consisting feasibility studies, the second stage is defined, consisting 2 phases, one for discharging the regional gas and the second for gas injection and storage. The storage capacity of one is 3/3 billion cubic meters of natural gas. The project started at the end of 2008. Another proper reservoir for injection is the Shurijeh which is located at north of Khorasan (Iran). In this reservoir, approximate tank capacity is eight quarters and the production ability is 40 billion cubic meter. In future, this reservoir is going to set as the second UGS reservoir in Iran.

In this work, a new additive, made of one type of homopolymer, named Polypropylene fiber, with some fiber glasses and other strongly resistant material to the tension, is added to the well cement to be used in UGS operations. In order to study the effects of this new additive on cement cracking, compressive strength, elasticity, free water, fluid loss, and density, lots of laboratory tests were conducted.

According to the studies and investigation of required tests, first of all, the samples were prepared at the well condition and their fluid losses, so free waters and densities were tested simultaneously with 24 and 48 h compression pressure tests. After 48 h, using strain–stress apparatus, the produced samples were tested to obtain the elastic thresholds and the elasticity coefficients. All of these tests and mixing methods were based on the API (American Petroleum Institute, 1990) standards.

2. Materials and methods

According to API Standard (American Petroleum Institute, 1990), cement class G was used in preparing all samples. This cement is associated with the highest alkalinity, the highest amount of C_3A and the shortest bond time.

A material named CD-1B was used as dispersant. This material reduces the friction between particles considerably; as a result, the cement becomes homogeneous, and its viscosity and frictional pressure against formation decreases. All over tests, rate of consumption was 1% by weight.

Two polymer additives, latex and fiber, were used to synthesize a total of fifteen cement samples. Composition of each sample is given in Table 1. The latex and fiber were made of styrene-butadiene and polypropylene, respectively. Sample A contains cement, dispersant and water. This sample is considered as the reference, with no more additive present in its composition. Samples C_1 and C_2 contained latex and fiber, respectively, while sample C_3 and C_4 contained both additives to study the combined effect of latex and fiber. Sample C_4 is typical cement used in field operations and has additional compounds, i.e. silica, salt, and weighting agent.

Table 1
Composition of prepared samples.

Sample	Constituents (% by weight)
A	Cement class G (64.5%) + Dispersant (0.18%) + Water (35.32%)
C_1	Cement class G (60.5%) + Dispersant (0.18%) + Water (27.42%) + Latex (11%)
C_2	Cement class G (64.6%) + Dispersant (0.18%) + Water (35.22%) + Fiber (0.05%)
C_3	Cement class G (60.45%) + Dispersant (0.18%) + Water (27.32%) + Fiber (0.05%) + Latex (12%)
C_4	Cement E (35.48%) + Silica (12.39%) + salt (3.8%) + Dispersant (0.035%) + Weighting agent (26.61%) + CFL (0.5%) + Fiber (0.027%)