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# An experimental study of silicate–polymer gel systems to seal shallow water flow and lost circulation zones in top hole drilling

Ahmet Ay [a,*], Ismail Hakki Gucuyener [a,1], Mustafa Verşan Kök [b,2]

[a] Karkim Drilling Fluids Inc., Turan Gunes Bul. 571. Cd. 606. Sk. No:24, Cankaya, Ankara, Turkey
[b] Petroleum and Natural Gas Engineering Department, Middle East Technical University, Inonu Bulvari, 06531 Ankara, Turkey

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ABSTRACT

Shallow water and lost circulation are frequently encountered problems during drilling top holes of oil and gas wells. Plenty of methods have been applied to overcome these problems. Among these methods, silicate based gels are one of the oldest. For this study, Sodium-Silicate based gel system is investigated experimentally and several aspects of the system are improved for efficient field applications. This improved gel system is deliberately delayed, multi-component system to be mixed as a uniform liquid at the surface facilities but desired to form gel structure where it is placed in the well. Gel slurries are composed of distilled water, Sodium-Silicate solution, polymer solution, lost circulation materials, weighting agent and organic initiator (initiating the gelation). In this study, effect of these components on gel time, gel quality and gel strength at room temperature is investigated as a function of their concentration.

In order to compare gelation time of different compositions, a new, easy and consistent gel time determination method is developed. Being based on vortex closure time, the method can be followed easily even by basic rig laboratories. Another new method is introduced to monitor long term gelation process by measuring turbidity (NTU) of the mixtures and plotting NTU versus time curves. In addition, unique observation codes are defined to compare the gel qualities of different compositions. For gel time and quality experiments, Sodium-Silicate concentrations from 3.5% to 15% by weight in the mixture were investigated and the concentrations range of 7.5–10% were found as applicable. It is determined that, gel time is getting higher as silicate–initiator ratio (SIR) increases for these optimum concentrations.

The system is improved by addition of two different polymer solutions. These polymers not only improve the elasticity of the final gels but also provide sufficient viscosity to keep weighting agent and/or lost circulation materials (LCM) in suspension. In addition, viscosity development curves obtained from rotational viscometer at various constant shear rates indicated that, gelation is accelerated by applied shear. Furthermore, HTHP filter press cell was modified by manufacturing new bottom cap with 1 mm diameter hole in center to determine the extrusion pressures of the gels and it was found that, extrusion pressure can be increased by the addition of fibrous type lost circulation materials.



## 1. Introduction

There are some drilling problems which are recognized from the beginning of the drilling operations. Among these problems, water flow into the well and lost circulation are still open for better and/or cost effective solutions.

Water flow into the well is one of the main problems encountered while drilling top holes of onshore and offshore wells. Water can flow into the well while drilling of over-pressurized sands or unconsolidated sediments which are mainly found in shallow zones of the offshore wells. This flow can cause serious problems by carrying portions of the water producing sand inside. Furthermore, in the presence of water, the well cannot be drilled by air or foam and it is difficult to implement desired cement job.

Lost circulation is another common problem in the drilling operations. It occurs when hydrostatic pressure of fluid column in the wellbore is higher than the formation pressure and is defined as the loss of drilling fluid into the formation. Lost circulation is

* Corresponding author. Current address: M-I Swaco, A Schlumberger Company, Kokstadflaten 4, 5257 Bergen, Norway. Tel.: +47 95092899.
E-mail addresses: aay@slb.com, ahmetay17@gmail.com (A. Ay), hakki@geos-energy.com, gucuyener0@gmail.com (I.H. Gucuyener), kok@metu.edu.tr (M.V. Kök).
[1] Current address: Geos-Energy Inc., 696 Sok. No: 20 Hilal Mah. No 20/1-3, Cankaya, Ankara, Turkey. Tel.: +90 312 4411107; fax: +90 312 4415129.
[2] Tel.: +90 312 210 48 91; fax: +90 312 210 48 93.

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usually accompanied by wellbore stability problems which can result in stuck pipe and even the loss of the well.

The drilling problems mentioned above are usually attempted to be solved by conventional cementing techniques. In this experimental study, gel system is developed as an alternative way to cementing. Gel applications have several advantages over cementing. Firstly, the application of the developed gel system at the field will not require any special equipment like pumping unit, batch mixer or silos which are required for a cementing operation. Moreover, cement slurries can only be pumped through open-ended pipes due to its high solids content. Gels however, can be pumped through the bottom hole assembly (BHA) which is already in the hole to drill the well. This means, at least two round trips can be avoided by choosing gel applications. Furthermore, cement drilling takes much more time than washing out the gel. Besides loosing time on drilling cement, bit life is also reduced.

On the other hand, there are obvious advantages of cementing over gel applications. Firstly, the cured cement is much stronger than the gel. Secondly, cementing is longer term solution when compared to gel applications. Finally, it is evident that, the problem solved by gel applications can also be solved by cementing while the vice versa is not valid for all cases.

Several types of gel systems have been widely used in the petroleum industry for different purposes including water shut-off, gas shut-off, plugging lost circulation zones, consolidation of loose formations, casing repairs, relative permeability modification/disproportionate permeability reduction and conformance control. Kabir (2001) listed the five common chemical sealing systems as: (1) resin and elastomers, (2) monomer systems, (3) polymer gels, (4) biopolymers and (5) inorganic gels. In this study, Sodium-Silicate gels together with the addition of organic initiator are designed for drilling applications.

As mentioned previously, using inorganic gels is not new to the industry. Mills (1922) introduced the first inorganic gels for the application to solve water production problems. The first silicate gels providing positively-controlled setting times on the other hand was introduced to the industry by Stewart and Eilers (1967). Herring et al. (1984) developed non-rig gas shut-off technique using coiled tubing and Sodium-Silicate gel. Shelley and Sciullo (1995) used silicate based gel system to plug the zone of initial producing zones to deepen the well for recompleting in another formation. Bauer et al. (2005) presented their experimental study on Sodium-Silicate gels by using encapsulated activator which forms silicate hydrate plugs when exposed the high temperature. Burns et al. (2008) introduced a new Sodium-Silicate–Polymer–Initiator (SPI) gel system which uses various polymers in the mixtures and organic initiator to start the gelation. Although their study was proposed for casing repairs and water shutoff, it constitutes the main background for the study presented here.

**Fig. 2.1.** Cell body, upper cap, modified lower cap, piston (white) and removal tool (yellow). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In this study, environmentally friendly gel system is developed with new gel features of adjustable viscosity and density. The slurry is liquid when mixed initially and forms a gel structure after a given period of time. Gel mixtures mainly composed of distilled water, Sodium-Silicate and organic initiator (required to initiate the gelation). The gels formed by using only these three components are brittle with no viscosity or density adjustment features. Two different types of polymers were used to improve the gel elasticity and to provide sufficient viscosity to keep LCM and weighting agent (barite) in suspension. LCM and barite are added to the system to improve the plugging efficiency of the gels and to adjust the density. All of the components in the proposed system are environmentally friendly and selected concerning their availability at the rigsite.

## 2. Experimental set-up and procedure

### 2.1. Equipment

Following equipment is used for the implementation of the study: (1) BARNSTEAD THERMOLYNE magnetic stirrer with a model number of SPA1020B, (2) OAKTON digital pH/Ion tester with an accuracy of $\pm 0.01$, (3) HF SCIENTIFIC DRT 15-CE Nephelometer type turbidimeter, (4) FANN 35SA Couette coaxial cylinder rotational viscometer with the R1-B1 combination and the standard F1 torsion spring, (5) FANN Model 140 Mud Balance, (6) PRECISA XT 2200C precision balance with a readability of 0.01 g and (7) modified FANN Filter Press HPHT 175 ML (Fig. 2.1).

HTHP Filter Press cell is modified for pressure extrusion experiments. Since the original opening of the bottom cap is not suitable for extrusion tests, another cap is designed with 1 mm hole in the center. Additionally, a piston with o-ring around is designed to distribute the pressure on the gel evenly. The outside of the piston is lubricated by grease providing easier movement inside the cell. A removal tool for the piston is also manufactured to remove the piston from inside of the cell.

### 2.2. Additives

Gel mixtures are composed of eight different additives provided by Karkim Drilling Fluids Inc. These are: (1) Distilled water, (2) Liquid Sodium-Silicate (SS), $Na_2O \cdot n(SiO_2)$, having a specific gravity of 1.39, solids fraction of 36.81% by weight which composed of 28.09% $SiO_2$ and 8.72% $Na_2O$, (3) Polymer-A (PA), an anionic linear synthetic co-polymer, (4) Polymer-B, slightly anionic biopolymer, (5) KAR-SEAL F, micronized cellulosic fibers, fine grade (PSD is given in Table 2.1), (6) KAR-SEAL M, micronized cellulosic fibers, medium grade (PSD is given in Table 2.1), (7) API test calibration barite, (8) Monohydrate citric acid ($C_6H_8O_7 \cdot H_2O$), having a molar mass of 210.14 g.

**Table 2.1**
Particle size distribution for KAR-SEAL F and KAR-SEAL M.

| *Particle size* | *KAR-SEAL F* | *KAR-SEAL M* |
|---|---|---|
| Greater than 425 μm | 1.05% | 2.55% |
| Between 250 μm and 425 μm | 8.35% | 32.80% |
| Between 180 μm and 250 μm | 9.95% | 25.55% |
| Between 150 μm and 180 μm | 22.65% | 16.55% |
| Between 125 μm and 150 μm | 23.05% | 7.35% |
| Between 75 μm and 125 μm | 20.30% | 9.20% |
| Between 45 μm and 75 μm | 8.45% | 3.30% |
| Smaller than 45 μm | 6.20% | 2.70% |