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Application of an improvised inorganic–organic chemical mixture to consolidate loose sand formations in oil fields

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ABSTRACT

Sand production in the reservoir has been acknowledged as a critical issue related to oil/gas fields for many years because it gives rise to many serious problems in oil/gas production. Sand production from wells can damage surface and subsurface equipment as well as it can reduce the well productivity, thus it can have an adverse effect on economy of the oil production. Sand control includes various mechanical and chemical techniques. Chemical method could alleviate various other problems like shutting of well, limitation regarding well bore size, clogging/plugging etc.

The present paper focuses on preparation of a mixed chemicals comprised of organic resins with various inorganic chemicals which is effectively able to convert loose sands into a compact one under suitable environment. Two organic resins UF, MF when mixed with inorganic silicate and curing agents showed much improved uniaxial compressive strength (UCS) (>1300 psi) while maintaining comparatively high porosity and permeability. Effects of various compositions of chemicals, pH, salinity, curing temperatures and times were investigated in detail and parameters were optimized for the best results. The experimental results showed that mixture of needs less amount of chemicals compared to the individual ones.

1. Introduction

The recovery of formation fluid such as oil/gas becomes troublesome from the underground formations having loose sand layers or zones (Harsenberger, 1972). Sand particles in these zones tend to migrate to the well bore during the recovery of the reservoir fluid. Thus, migrated sand particles would lead to stop the flow of formation fluid flow towards the well bore (Wiechel et al., 1985) and lead to a decline in the oil recovery rate that is economically unattractive to continue production further (Weaver et al., 1999). Sand particles are often carried along with formation fluid through the equipment which are being used to recover the formation fluid up to the surface. The abrasive nature of these sand particles can cause damage to the expensive equipment such as separator, pipes, pumps, etc., which can inflate the economy of production (Harsenberger, 1972). There are several factors that increase the sand migration such as driving factors that include in-situ stress and its variation, reservoir fluid velocities, etc.; resisting factors like friction, cohesion, capillary actions; and operational factors that include differential pressure and production rate (Ranjith et al., 2013).

A number of techniques which available in industry to tackle sand production problems from the oil well are maintenance and workover, production rate control, mechanical methods and chemical consolidation (Aggour et al., 2007). Mechanical methods use gravel pack screens, filters, perforated or slotted liners, etc. around the wellbore. Mechanical devices usually bound only larger sand particles and are not completely effective to restrict the flow of fine particles from the formation. Furthermore, it interferes with the various type of completions and workover operations (Nguyen and Rickman, 2009). Chemical sand consolidation method is one of the common forms of screen-less sand consolidation which involves the injection of reactive chemicals into a naturally unconsolidated formation (Acock et al., 2003). The role of the chemical is to bind the sand grains together at their contact point that make up the formation matrix, increasing its UCS sufficient to withstand the drag forces while maintaining the sufficient absolute permeability to achieve the viable production rates (Friedman and Surles, 1991).

Usually chemicals are in the liquid form when injected into the unconsolidated formation layer, and a curing agent or catalyst is required for hardening (Brooks et al., 1974; Curtice and Harnsbereger, 1976). There are two types of catalytic systems: (1) internal and (2) external. In internal catalytic system catalyst is mixed with the chemical on the surface before injection; then cured/harden at suitable temperature and time. The external catalytic

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system involves injection of catalyst after the binding agent is in place. The disadvantage to the external system is premature hardening in the work string, whereas in internal all chemicals will be in contact with the catalyst required for efficient curing. The amount of chemical and its curing agent should be carefully chosen and controlled for the specific well conditions (Bezemer and Mejis, 1966). So far most of the researchers used polymers and plastics like phenolic resin, furfuryl alcohol, furan resins, epoxy resins, and polyacryl amide to control it (Spain, 1967; Copeland et al., 1969; Harnsberger, 1973; Vogel and Beach, 1957; Hess, 1972; Harnsberger, 1978; Surles and Fader, 1995; Nguyen, 2006; Sparlin, 1972; Friedman and Surles, 1989; Parlar et al., 1998). Espin et al., (2003) and Ogolo et al., (2012) applied nanoparticles to consolidate unconsolidated formations. Urea-formaldehyde, melamine-formaldehyde, combination of these two, and organic and inorganic silicates have been used as a binding agent for the sand consolidation process (Young, 1965; Jennings, 1989; Wasnik et al., 2005; Rockwell, 1970; Anthony, 1983; El-Sayed et al., 2001). Lucas et al. (2011) and Kouassi et al. (2011) described the interaction between the silica sand and the sodium silicate solution during the consolidation mechanism.

As discussed so far chemicals used in sand consolidation are either purely organic or inorganic in nature. Organic resins given good consolidation but required in huge quantity associated with pumping problem. Durability of sand consolidated with inorganic/organic silicates is a big issue in the field thus not economical much. Application of silicates is not new in oil industry. It has been used continuously in EOR processes for profile modification and as a consolidating material in sand control. Tiszai et al. (1999) had applied the silicates and the polymer or humates for water shut-off and profile modification. Thus, it was thought to combine the silicate with resin solution as a consolidating material which could solve the pumping problem associate with high density and high viscosity polymer as well as to resolve the durability issue of inorganic silicate. The present experimental results prove to be a better binding agent compared to the individual one. Thus, in the present investigation mixture of silicate and resins were used for consolidating sand which results in better durability with high UCS. Effects of composition of various inorganic compounds i.e. potassium silicate, Ammonium chloride, Aluminum sulfate, sodium bi-carbonate and organic compound like urea and melamine–formaldehyde were investigated. The effects of temperature, consolidation time on the strength of consolidated sand, permeability retention and other characteristics of sand formation are studied in detail and their effects were observed and optimized for the best result.

2. Materials and methods

2.1. Materials

Urea–formaldehyde [UF] and melamine–formaldehyde [MF] were procured from Otto-Chemie, Berlin. Potassium silicate [PS] was supplied by National Chemicals, India. The curing agent such as: ammonium chloride [AC] (NH_4Cl), aluminum sulfate [AS] [$Al_2(SO4)_3$] and sodium bi-carbonate [SBC] ($NaHCO_3$) were used to accelerate the curing process. Sodium hydroxide, hydrochloric acid, and sodium chloride were used to maintain the pH and salinity respectively. These chemicals were purchased from Loba Chemie Laboratory Reagents & Fine Chemicals, India. Formation sand (S_1) was obtained from a sand producing well in Nazira oil field (Assam), India. Regular granular sand (S_2) was brought from the bank of river Damodar, Jharkhand, India. All the chemicals used in the study are of analytical grade and used without further purification.

2.2. Experimental method

2.2.1. Sand core sample preparation and compressive strength measurement

The polyvinylchloride (PVC) molds of size 1" × 2" ($D \times L$) were utilized to prepare the synthetic core samples. These molds were used to measure the amount of dried sand grains. 10 ml volume of chemical solutions were used to bind the sand grains together. To prepare the consolidated sand core samples the following steps were followed:

1. Sand particles were first washed with brine solution and then dried.
2. Dried sand particle were then sorted using sieve shaker.
3. Selected chemicals e.g. UF, MF, PS, ammonium chloride, aluminum sulfate, sodium bi-carbonate, and distilled water were mixed in predetermined proportion.
4. Required amount of sand was blended with the chemical mixture of particular composition using blender for 10 min to insure complete mix.
5. The prepared mixture was then poured in to the greased cylindrical molds.
6. Molds were kept in an oven for the curing process for 24 h and temperature was gradually increased to simulate wellbore temperature up to 100 °C.
7. Continuous water was added during curing process maintained at the prevailed temperature.
8. After the curing, sand cores were cooled down and dismantled from the molds.

UCS of the core samples was measured by the compressive Strength testing equipment (AT-106, Accro-Tech Scientific industries, India). The compressive strength is calculated as follows:

$$\mathrm{UCS} = \frac{F_{\max}}{A} \tag{1}$$

where,

UCS = uniaxial compressive strength;
F_{max} = maximum force applied before or at the time of failure;
A = cross sectional area of the core sample.

2.2.2. Porosity measurement

Initially before the consolidation treatment, the density of sand was determined first and then packed with known weight of sand. Porosity of unconsolidated clean sand was then measured from these known grain volume and bulk volume. Porosity of the prepared sand core was measured using TPI-219 Helium porosimeter. The helium porosimeter uses the principle of gas expansion, as described by Boyle's law.

Porosity can be calculated from following mathematical formula:

$$\phi_e = \frac{V_b - V_g}{V_b} \tag{2}$$

$V_g = V_1 - V_2$, the volume of the grain and non-connected pores, cm^3;
V_b = the bulk volume of core, cm^3;
V_1 = the volume of the calibrated chamber (matrix cup) of porosimeter without core, cm^3;
V_2 = the volume of the calibrated chamber (matrix cup) of porosimeter with core, cm^3.

2.2.3. Permeability measurement

The permeability of the core samples was measured by using Ruska air permeameter (model no. 1370CZ1A3AZZ17). Air permeability can be derived from a modified version of Darcy's law.