Development of an Environmentally Friendly and Economical Process for Plugging Abandoned Wells (Phase II) –Annual Report

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Title: Development of an Environmentally Friendly and Economical Process for Plugging Abandoned Wells (Phase II)
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Objectives: This was a continuation of the project entitled "New Process for Plugging Abandoned Wells (EPA-R-82-7015-01-0)." The objective of Phase II of this project was to develop a practical process/technique to place fly ash slurry developed in the previous project, and place it in the wellbore under the in-situ conditions, and also to verify its plugging quality by using the laboratory and actual well test data. Furthermore, the technology to place fly ash slurry through coiled tubing was to be developed to minimize the environmentally hazardous conditions and maximize economic benefits by eliminating the conventional rig-up.

Progress Summary/Accomplishments: The phase II of this project was successfully completed, except the field tests. These tests are planned and will be completed soon. It was found that the fly ash slurry had sufficient thickening time and could be pumped successfully through coiled and straight tubing. Pumping through coiled tubing will minimize the environmentally hazardous working conditions and maximize the economic benefits by eliminating the conventional rig-up. By performing tests for shear bond strength, hydraulic bond strength, and gas permeability, it was confirmed that Class C fly ash grout could make a sound plug to keep fluids from communicating in the abandoned well. The fly ash plug itself showed a low permeability. Furthermore, two abandoned wells have been identified and will be plugged with this newly developed fly ash plugging technology. Thus, this newly developed Class C fly ash plugging technology will be verified as a secure method to plug abandoned wells in an environmentally friendly and economical way.

Introduction: The importance of plugging to abandon a well is to prevent contamination of groundwater aquifers by surface water, oil or gas seepage, or brine formations below the groundwater aquifers. Cement grout is the present material used in plugging. The Class C fly ash is known to have properties very similar to cement. Presently, only about half of the fly ash produced by the various coal-fired power plants in the state of Oklahoma is used and the rest must be treated as a waste product and disposed of in landfills. Much of this fly ash is the higher lime content, more cementitious, Class C fly ash. Furthermore, the fly ash is more economical as it costs only one-tenth of the cost of cement. According to the study "Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Significance" Fact Sheet FS-163-97 of October of 1997, from the U.S. Geological Survey, the radioactive elements in coal and fly ashes should not be sources of alarm. It means that fly ash does not have any harmful material among its components, which could make it hostile to subsurface environment. Therefore, the use of a fly ash grout as a plugging material will be an environmentally friendly and economical process for plugging abandoned wells.

Class C fly ash samples were selected from the five coal-fired power plants located in Oklahoma.

Methods: The following tests were performed with five different fly ash samples at the Well Construction Technology Center (WCTC) of the University of Oklahoma.

Chemical and Physical Analyses: The objective of these tests was to confirm the classification of fly ash samples and to verify the representation and consistency of samples from different fly ash sources.

Thickening Time Tests: The objective of these tests was to determine the duration given cement slurry remains as a pumpable fluid under the given laboratory conditions, and thus, serve as a means of comparing it with the cementing materials. Tests were performed in accordance to the Section 9.3.3 of API[1]Spec 10A.

Rheology Tests: Rheology tests were performed with the Bohlin CS-50 rheometer available at OU's WCTC. It is a controlled stress instrument in which a constant shear stress is applied and the resultant shear rate is measured. The concentric cylinder geometry was employed for these measurements. The effect of temperature on the fly ash slurry rheology was examined at 80, 100, and 120 ^{o}F. These temperatures represent the ambient, median, and maximum bottom hole circulating temperature, respectively. The experiments were limited to an ambient pressure because rheological properties are not very sensitive to pressure.

Frictional Pressure Loss Tests: The objectives of these experiments were: (1) to confirm the pumpability of fly ash slurry through coiled tubing, and (2) to obtain the frictional pressure loss data for fly ash slurry.

Wellbore Fluids Contamination/Compressive Tests: The objective here was to check the contamination between wellbore fluids and fly ash slurry. If the wellbore fluid significantly affects the compressive strength of fly ash sample (<500 psi), an appropriate wellbore fluid removal technique is then selected.

Permeability Tests: The objective of these tests was to determine the permeability of fly ash core samples and cement core sample for comparison.

Bonding Tests: The objective of these tests was to determine the shear bond and hydraulic bond strengths of fly ash slurry.

RESEARCH RESULTS:

Confirmation of Classification and Verification of Consistency of Fly Ash Samples: The results of chemical and physical analysis of fly ash samples revealed that all fly ash samples meet ASTM[2] C 618 specifications for Class C fly ash. The most important chemical component of Class C fly ash is the lime (CaO) content, which is a cementitious material. The average value of lime content was 27 %. The magnesium oxide (MgO) provides good swelling characteristics and increases the shear bond strength. The average value of MgO in fly ash samples was 6.2 %, which is higher than 1.14% in Class H cement. The carbon content, which is indicated by the loss on ignition, will affect water demand since the carbon absorbs water. All fly ash samples showed very low values (< 0.42 %) of carbon; therefore, it should not adversely affect the water content of fly ash. The fineness (+325 mesh) of all five fly ash samples was lower than 19.9 %. ASTM C-618 Class C fly ash requirement is 34 % maximum. The results showed that the fly ash is very uniform in size and should make a good homogeneous mix.

No significant difference between the Oklaunion fly ash samples collected in 2000 and 2003 was found. This means that the consistency of the fly ash sample is good, at least in the case of the Oklaunion fly ash.

Rheology of Fly Ash Slurry: The rheology of all fly ash slurries was influenced by temperature. Compared to the cement slurry, all fly ash slurries showed higher shear stress values, except the Oologah slurry. It means that fly ash slurries require higher force to sustain a given flow rate than the cement slurry. At higher temperature, the viscosity of each slurry decreases. The rheological behavior of all fly ash slurries evaluated was adequately described by the power law non-Newtonian fluid model.

Pumpability of Fly Ash Slurry through Coiled Tubing: From the thickening time tests it was concluded that all fly ash samples exceeded the criterion of adequate working time of 2 hours. The Muskogee fly ash sample was selected for the pumpability test because it showed the least thickening time (3 hours) and was the second most viscous slurry. If this slurry can be pumped without problems, the others should be pumped as well.

Figure 1 shows the plot of Fanning friction factor versus generalized Reynolds number calculated from the experimental data of Muskogee fly ash slurry tested in 1 ½ in. coiled and straight tubing. The coiled tubing friction factors were in general 18 % greater than the straight tubing friction factors. It can be seen from this figure that both the straight as well as coiled tubing data sets are below the corresponding Drew and Srinivasan correlation, respectively. The fly ash slurry data from the straight tubing were corrected (13%) for the pipe roughness effects. The fly ash slurry exhibited 6% drag reduction[3] in both the straight and coiled tubing. Thus, the fly ash slurry was slightly easier to pump than its base fluid, i.e. water. The Muskogee fly ash slurry exhibited drag reduction because it contained 0.5 % retarder, which was a polymer base. Generally, the base fly ash slurry itself does not have a drag reduction characteristic.

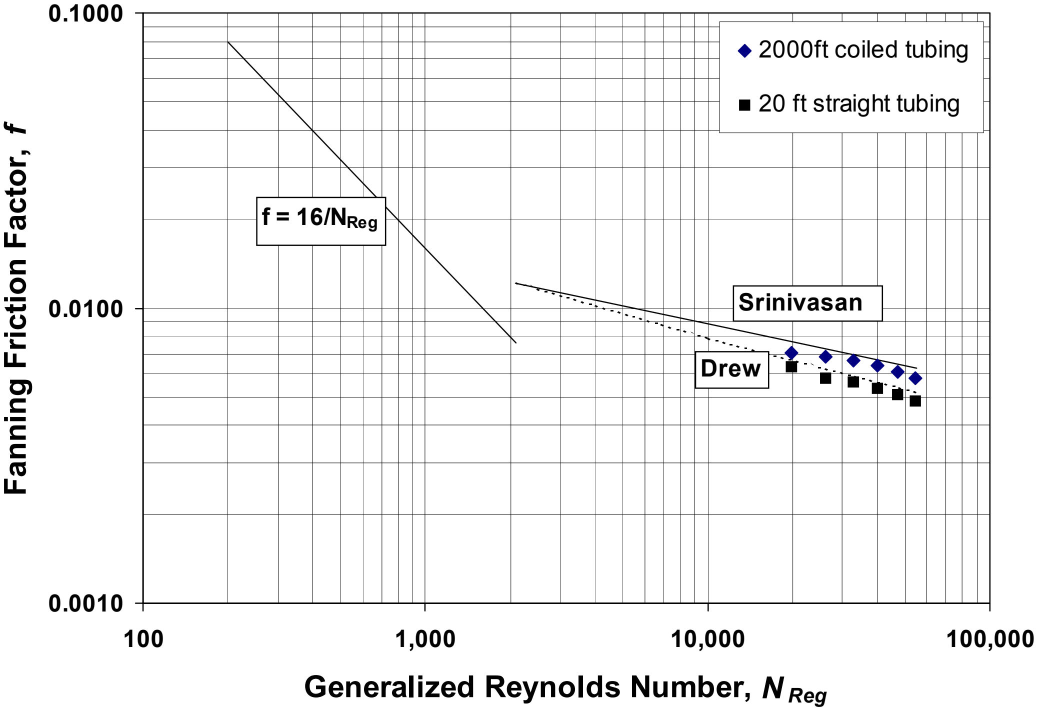

Fig. 1 Friction Factor vs. Generalized Reynolds Number - Muskogee Fly Ash Slurry

Effect of Wellbore Fluid Contamination on Compressive Strength: In the presence of API brine (2.5 % $CaCl_2$ and 8.5 % NaCl by weight of fresh water), all fly ash core samples showed low compressive strengths (Table 1). Even a 5 % mix of API brine resulted in a dramatically lower compressive strength. These tests were simulated using much worse conditions than it is expected in the field because the complete fly ash slurry was well mixed with brine. This could make a low strength fly ash plug. In the field, a large amount of fly ash slurry will be used for plugging a well, which would result in a weak core locally where the contamination with wellbore fluid occurs. The contamination can be dramatically reduced by employing a proper placement technique.

Table 1 – Results of Compressive Strength (psi) Tests

Fluid Mixture Fly ash / API brine	Fly ash sources			Curing Time
	Muskogee	Oklaunion	Redrock	
100 % fly ash	1786	1108	1544	7 days
95 / 5	503	86	60	
75 / 25	52	44	33	

Bonding Characteristics/Permeability: Sealing recommendations are often made on the basis of compressive or tensile strength of set material on the assumption that a material satisfying strength requirements (compressive strength >500 psi) will also provide an adequate bond. However, this assumption cannot always be valid[4].

The shear bond strength of the set slurry is a measurement of the force required to initiate movement of the plug in the hole. The hydraulic bond strength is a measurement of the hydraulic pressure required to initiate leakage of fluid between the plug and the wall of the wellbore[4,5] (Fig. 2).

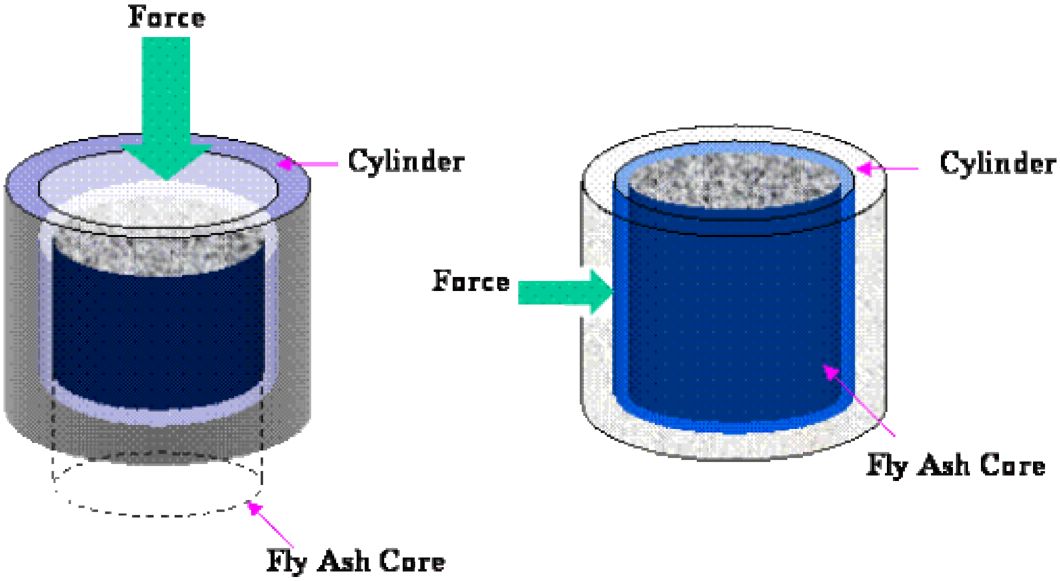

Fig. 2 - Shear / Hydraulic Bond Forces on Fly Ash Plug

The Hugo fly ash showed the highest shear bond strength of 1,132 psi, the Muskogee fly ash was second at 1,070 psi, and the Oologah fly ash showed the lowest strength of 97 psi. The shear bond strength of Class H cement was 1,285 psi. Evans and Carter[5] tested the bond strength of Class A cement to rusty steel pipe. They reported 141 psi for one day curing at 80 °F, and 422 psi for 2 days of curing at the same temperature. Comparing the results of cement with the results of fly ash, except the Oologah sample, indicate that the shear bond strength of fly ash is reasonable.

The test results of the Muskogee fly ash sample from the short and long core holders were very comparable at 1,070 psi and 1,103 psi, respectively. Thus, it confirms that the length effect can be neglected for bond strength test.

The range of hydraulic bond strength of all samples except the Oologah sample was from 1,500 to 2,100 psi. These bond strengths were determined using a pipe cell. If a thick mud layer is present at the fly ash plug and pipe interface, bond strength will be greatly reduced; however, there are methods[6,7] to increasing the efficiency by removing the mud layer. Both shear and hydraulic bond strengths measured showed a good relative agreement between fly ash samples (except the Oologah sample) and a Class H cement sample. Evans and Carter[5] reported the hydraulic bond strength of 500 to 700 psi for Class A cement to rusty steel pipe with two days of curing at 80 °F.

Gas permeability is another vital parameter for checking the quality of a plugging material itself. All fly ash samples exhibited low permeability and they were of the same order of magnitude as Class H cement. The Muskogee sample showed the lowest permeability of 0.062 md among all fly ash samples and it was also lower than Class H cement (0.197 md). As a result, it is evident that the gas migration through fly ash plug in the wellbore, if any, will be at minimal.

CONCLUSIONS:

1. While the chemical/physical properties of five different fly ash samples varied somewhat depending on the power plant, the compositions of all fly ash samples were consistent. For example, the CaO content and fineness of the Oklaunion fly ash sample showed no significant difference in chemical/physical properties between the years 2000 and the 2003. Concentrations of toxic trace elements such as As, Ba, Cd, Cr, Pb, Hg, and Se in three fly ash samples (Oologah, Muskogee, Oklaunion) were far below the US EPA – TCLP regulatory limits. This confirmed that fly ash is not a hazardous material and can be used for plugging abandoned wells.
2. The rheological behavior of fly ash slurries can adequately be described by a pseudoplastic non-Newtonian Power Law fluid model. Rheological properties of fly ash slurries were found temperature dependent.
3. The fly ash slurry was successfully pumped through 2000 ft of 1 ½ in. coiled tubing and 20 ft of 1 ½ in. straight tubing. It exhibited approximately 6 % drag reduction in both coiled tubing and straight tubing.
4. The shear bond strengths (except Oologah sample) ranged from 763 to 1,132 psi and were in reasonable agreement to the similar value reported for the cement plug (1,285 psi). The effect of the length of a core holder on bond strength was found to be insignificant. The hydraulic bond strengths of fly ash plugs (except Oologah sample) ranged from 1,500 to 2,100 psi and showed relatively good agreement to Class H cement which had 1,250 to 1,500 psi of hydraulic bond strength.
5. All fly ash samples exhibit significantly low permeability ranged from 0.062 to 0.521 md and they are of the same order of magnitude on Class H cement.

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Publications/Presentations:

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2. Shah, S.N., and Jeong, Y.T.: "Development of an Environmentally Friendly and Economical Process for Plugging Abandoned Wells", 10th International Petroleum Environmental Conference, Houston, TX, Nov. 11-14, 2003.

Future Activities: Two identified wells will plugged with the optimal fly ash slurry formulation and the practical process/technique to place the fly ash slurry developed in this project

Supplemental Keywords: Land, Fly ash, Abandoned well, Plugging technique, Petroleum industry, Coiled tubing, Groundwater aquifer, Engineering, Innovative technology, Cost benefit, Southwest, Oklahoma.

Relevant Web Sites: www.pttc.org, www.ou.edu/wctc, ipec.utulsa.edu