New Process for Plugging Abandoned Wells (Phase I) –Annual Report

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Title: New Process for Plugging Abandoned Wells (Phase I)
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Description:

Objectives: The primary goal of Phase I of this project was to develop the optimum grout formulation for plugging material by performing laboratory tests of the fly ash samples selected from five coal-fired power plants in Oklahoma. To ensure a comprehensive understanding of the fly ash grout characteristics as a cement material, extensive experiments were performed.

Progress Summary/ Accomplishments: The phase I of this project was successfully completed. An optimum fly ash slurry formulation has been developed from this study. The physical characteristics of this formulation are compared with the characteristics of Class H cement slurry. All fly ash sources in this study show the compressive strengths of fly ash plugs in excess of 500 psi after one week of curing time. The pumpability test also was performed and thus, verifing the ability to pump plugs of fly ash grout through coiled tubing and straight pipe.

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 as shown in Fig. 1 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.

Particle Size Distribution Tests: The objective of these tests was to determine the particle size distribution of each fly ash source. The test standard applied in these tests was ASTM C 136 "Sieve Analysis of Fine and Coarse Aggregates".

Compressive Strength Tests: There were two main objectives of these tests. One was to find the optimum formulation of fly ash, to produce high compressive strength fly ash plug. The other was confirming that the compressive strengths of dried samples are satisfactorily met with the field acceptance criterion (compressive strength > 500 psi). Tests were performed in accordance to the Section 7 and Section 8 of API Spec. 10A.

Thickening Time & Free Water Tests: The objective of these tests was to determine the duration a 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 Spec 10A. The objective of free water tests was to check the amount of water used for slurry formulation

Product Durability tests: The objective of these tests was to verify that the mean saturation coefficient of fly ash sources was not significantly different from that of Portland cement. Three fly ash sources (Oologah, Muskogee, and Red Rock) were selected for the test. All samples were put in a water curing device at 100 ^{o}F for one week. The water-cured samples were dried in a drying oven at 100 ^{o}F for one week. API brine water and acidified water (pH≅ 5.0) were prepared. The dried samples were then immersed into two different solutions for one week. The test standard ASTM C 216 – 97: "Standard Specification for Facing Brick" was applied on this product durability test.

Fluid Loss Tests: The objective of these tests was to determine the filtration rate, which was indicative of the rate at which permeable formations are sealed by the deposition of a mud cake after being set by fly ash plugs. The test was performed in accordance with API RP 10 Appendix .

Rheology Tests: These tests were performed to measure the fluid properties of the fly ash slurry. A model 35 Fann viscometer was used to determine the rheology.

Frictional Pressure Loss Tests: The objectives of these experiments are: (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. Optimum fly ash formulation developed in this study (30% water and 1.0% retarder and 0.5% dispersant by weight of fly ash) was pumped through a 2,000 ft of 1 ½-in. coiled tubing and a 20 ft section of straightened 1 ½-in. tubing. The flow loop for pumpability test is shown in Figure 2.

RESEARCH RESULTS:

Characterization of Fly Ash: The results of sieve analysis showed that most grains are distributed in fine particle area (below 45 μm – equivalent to US sieve No. 325). Both physical and chemical analyses were performed according to the ASTM C 618 "Fly Ash and Raw or Calcined Natural Pozzalan for Use as a Mineral Admixture in Portland Cement Concrete". These data showed that the fly ash from each source is insignificantly different from each other.

Optimum slurry formulation: The down-hole performance of cement slurries is primarily influenced by temperature and pressure. They affect how long the slurry will be pumpable and how well it will develop the strength to plug the well. Temperature has more pronounced influence. For the application of fly ash grout to shallow wells abandonment plugging, the applicable depth was designed to less than 6,000 ft because an average of 6,370 oil, gas, and dry holes were drilled in Oklahoma each year with an average depth of 5,501 ft from 1980 to 1991. The influence of pressure upon the pumpability of fly ash slurry has not been studied. However, the results with cement slurry show that the influence of pressure is negligible within 6,000 ft of depth. During abandonment process, there is less cooling because there is less well fluid preceding the slurry. Thus, the pumpability of fly ash slurry is shorter during abandonment well plugging than casing cementing at the same depth.

The compressive strength test results showed that the "Red Rock" sample had the highest strength, and "Oologah" sample had the lowest strength. Two fly ash sources were then selected from the pre-test: "Oologah" and "Muskogee". "Oologah" showed the lowest compressive strength and Muskogee showed the second highest compressive strength. The reasons for these selections are that (1) if the test results of "Muskogee" are acceptable, then the "Red Rock" sample, which showed the highest compressive strength, can be considered as acceptable, (2) if the test results of "Oologah" are acceptable, all fly ash sources can then be acceptable for this study. An increase in water curing time on both samples increases the compressive strength. The compressive strengths of samples were over 500 psi after one week of curing time, regardless of water bath temperature. This compressive strength (500 psi) is generally accepted as a minimum strength for both production and abandonment plug by the oil and gas industry. The compressive strengths either with 0.5 percent of dispersant or with 0.5 percent of retarder were over 500 psi after one week of curing time.

Two representative samples of fly ash slurry with 0.5% (wt.) dispersant showed the thickening time of 15 min. However, the fly ash slurry with 0.5 % dispersant and 0.5 % retarder showed too long thickening time (over 4 hrs). The fly ash slurry with 0.5 % retarder by weight of fly ash showed an appropriate thickening time of 2 hrs. The thickening time acceptance criterion for Class H or Class A cement is 1.5 to 2.0 hrs in order to have adequate working time as specified in Table 11 of API Spec. 10A. The same acceptance criteria was applied to fly ash slurry in order to decide the optimum formulation. The test with 0.5% retarder met this criterion.

The results showed that free water content in every fly ash source were within the acceptance criterion (Sect. 6.2 of API Spec. 10) for Class G & H or Class A cements (less than 3.5 ml free water). Thus the optimum slurry formulation obtained is 0.5% retarder and 30% water by weight of fly ash.

Physical properties of The Formulated Fly Ash Surry: Tukey Tests between Oolgah vs. Class H cement, Muskogee vs. Class H cement, and Red Rock vs. Class H cement were conducted on the saturation coefficient. The analyses of variance (ANOVA) were performed with Generalized Linear Model (GLM) by using SAS program. The results show that the saturation coefficients of all fly ash samples were statistically ($\alpha = 0.05$) not different from that of Class H cement. Moreover, the results of Tukey multiple comparison tests clearly showed that the mean values of all samples (including Class H cement) were in the same group for both solutions.

These tests were performed only as reference to verify that the compressive strength of fly ash samples was over 500 psi under these extreme conditions, which should be an acceptable requirement as a plugging material. Figure 3 illustrates that even under acidified condition, which is the most severe situation, the fly ash samples do not reduce their strengths significantly. Red Rock sample showed the highest compressive strength among the fly ash sources.

The range of fluid-loss values of fly ash slurries is 67 to 130 ml. in 30 minutes. These values are obtained without adding any additives. These values are also within recommended value for cement slurry.

Using the Fann viscometer data, fluid properties shown in Table 1 were calculated for Power law model $[\tau = k_v(\dot{\gamma})^n]$. Muskogee sample showed less viscous and good thickening time characteristics. Thus, the Muskogee slurry was chosen for frictional pressure loss test.

The experimental friction factor data of the fly ash slurry were compared with the predicted friction factors from the Drew correlation and are presented in Fig. 4. It indicates that the experimental data points for the fly ash slurry have less values than the Drew correlation. It suggests that the fly ash slurry exhibits some drag reduction and can be pumped using coiled tubing and straight tubing.

CONCLUSIONS: An optimum fly ash slurry formulation has been developed in this study. This formulation meets or exceeds the industry requirements even under the most severe cases (brine or acidified water conditions). All fly ash sources selected in this study showed the compressive strengths of fly ash plugs in excess of 500 psi after one week of curing time, regardless of the curing temperatures which ranged from 80 to 120 ^oF. This compressive strength (500 psi) is generally accepted as a minimum strength for both production and abandonment plug by the oil and gas industry. Fluid loss of each fly ash source was within a recommended value of fluid loss without adding any special filter loss control additives. The pumpability test was performed in order to verify the ability to pump plugs of fly ash grout through coiled tubing and straight pipe for maximum bonding and plugging. The proof of pumpability of the slurries provides a bright future for fly ash slurries since coiled tubing can be used to place the slurry at the wellsite without the use of conventional rig.

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Publications/Presentations: Shah, S.N. and Cho, H.: "Development of an Environmentally Friendly and Economical Material for Plugging Abandoned Wells", presented at the 8th International Petroleum Environmental Conference, Houston, Texas, Nov. 6-9, 2001.

Future Activities: A practical process/technique to place the fly ash slurry developed in the previous project will be developed. Fly ash slurry needs to be placed in the wellbore under the downhole conditions, and also its plugging quality be verified by using both the laboratory and actual well test data. Furthermore, the technology to place a fly ash slurry through coiled tubing will be developed to minimize the environmentally hazardous work conditions and to maximize economic benefits by eliminating the conventional rig-up.

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

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Fig. 1 – The Location of Fly ash Collection

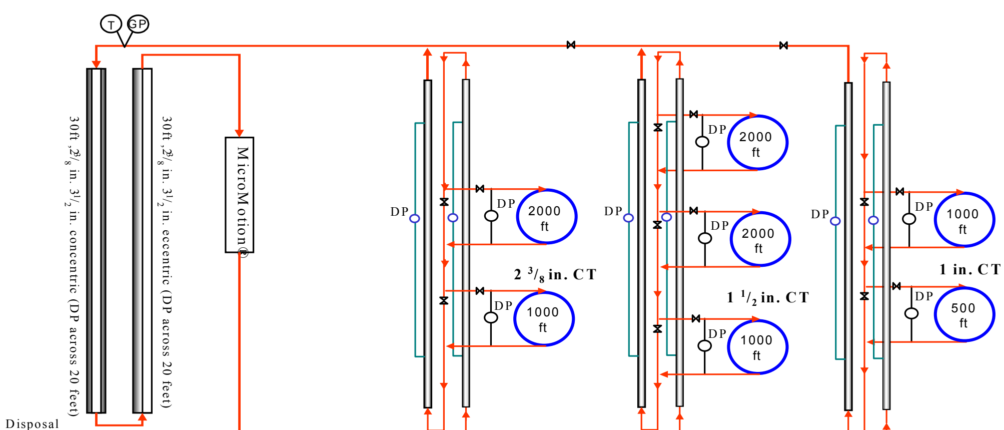

Fig. 2 – Schematic of Experimental Setup of Flow Loop at WCTC, Norman

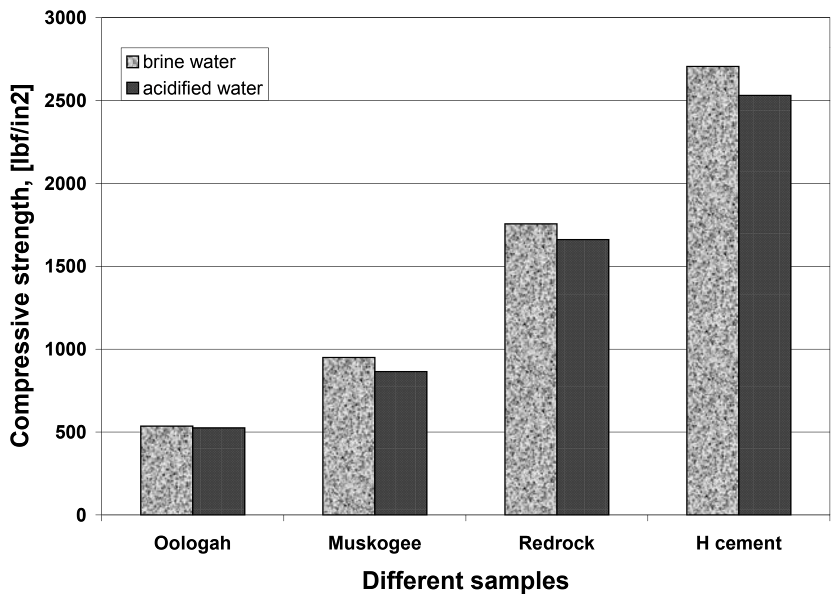

Fig. 3 – Compressive Strengths after Durability Tests

Table. 1 – Fann 35 data for the fly ashes (R1B1, #1 spring)

Sample	Oologah	Muskogee	Oklaunion	Hugo	Red Rock
n	1.035	1.058	0.969	0.971	0.983
K_v	0.000713	0.000558	0.001456	0.001358	0.001150

Fig. 4 – Fanning Friction Factor vs Reynolds Number for the Muskogee Slurry