

Period Covered by the Report: November 1, 2003 – January 31, 2004

Date of Report: March 1, 2003

EPA Grant Number: EPA-R 83-0633-01-0 (Phase II)

Title: Development of an Environmental Friendly and Economical Process for Plugging Abandoned Wells

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Project Period: May 1, 2003 – April 30, 2004

Project Amount: \$ 135,803

Research Category: Plugging of abandoned wells

This project is the continuation of the project titled “New Process for Plugging Abandoned Wells (EPA-R 82-7015-01-0)”. In this third quarterly report, results of the wellbore fluid contamination tests of fly ash samples are described and discussed. Depending on the effect of wellbore fluid contamination, the effective removal technique is then determined. The permeability of fly ash plugs is determined and compared to Class H cement results.

Wellbore Fluids Contamination & Compressive Strength Tests

The objectives of these tests are to check the contamination between wellbore fluids and fly ash slurry. If the wellbore fluid significantly affects the compressive strength of fly ash sample (less than 500 psia), an appropriate wellbore fluid removal technique is then selected.

A major problem in plugging abandoned well is the effective removal of wellbore fluids during plugging operation. The quality of plugging is influenced by wellbore fluid contamination, dilution, chemicals, and the slurry bonding to the filter cake. Some degree of wellbore fluid and fly ash slurry contamination will occur during plugging jobs.¹ Contamination is evident when soft cementing is observed in drilling out the plug. The most satisfactory means of combating the effects of wellbore fluids on well plugging grout will be to minimize contamination of the fly ash slurry with treated fluids during plugging operation. Most of the abandoned wells contain mainly salt water with possibly some drilling mud and residual oil, present.

In this task, the effect of contamination between wellbore fluids and fly ash slurry is checked. API brine as a wellbore fluid is prepared with 2.5 % CaCl₂ and 8.5 % NaCl by weight of fresh water. The fly ash slurries are prepared using the optimum formulation (30 % water, 0.5 % retarder by weight of fly ash). Mixtures of a fly ash slurry and API brine are prepared by the weight ratios of API brine to fly ash slurry.

Table 1 – The Mixture Ratios of Fly Ash Slurry to API Brine

Fluid Mixture Fly ash / API brine	Fly ash sources			Curing Time
	Muskogee	Oklahoma	Redrock	
100 % fly ash	xx	xx	xx	7 days
95 / 5	xx	xx	xx	
75 / 25	xx	xx	xx	

The ratios are prepared according to Table 1. This test procedure is similar to the procedure of compatibility of wellbore fluids in the Section 16 of the API² Recommended practice 10 B. After curing for a week at ambient temperature, the compressive strength of each fly ash sample is measured. The procedure followed was in accordance with the Section 7 of API³ RP 10.

The results of compressive strength tests of saturated core samples with the mixture of wellbore fluid and fly ash slurry are presented in Table 2. In presence of API brine, all fly ash core samples showed low compressive strengths. 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 the 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. Then contamination of fly ash slurry with the wellbore fluid can be dramatically reduced by employing a proper placement technique.

Table 2 – The Results of Compressive Strength (psi) Tests

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

For plugging abandoned wells, wellbore fluid removal technique is required when the fly ash plug in a wellbore is significantly weakened. The fluid removal techniques for plugging abandoned wells are not yet fully understood. Usually, wellbore fluid removal process is overlooked and not considered in plugging abandoned wells. From the published literature, some suggestions are drawn. Fly ash slurry contamination is avoided by pumping compatible water based fluids with both the fly ash slurry and wellbore fluids^{4,5}. Preflushes are designed to clean the wellbore fluids such as drilling mud, cutting, brine, and pumped into the wellbore in front of the fly ash slurry. They are pumped either in laminar flow or turbulent flow.

Washes are thin, usually water-based fluids containing surfactants and mud thinners, designed to thin and dispersed the mud so that it can be efficiently removed from the hole. The simplest form of a wash is fresh water. However, for a more efficient thinning and dispersion of the mud, chemical washes, which contain a mixture of dispersants and surfactant, are more commonly used.

Spacers are fluids of a controlled viscosity, density and gel strength that form a buffer between the cementing slurry and the drilling fluid. They help in the removal of the drilling fluid during cementing operations.

Above all, wellbore fluids removal techniques should be taken under careful consideration because it is an additional cost in plugging operation. The wellbore fluid contamination also can be minimized when the fly ash slurry is placed in a well by a suitable placement method, as reported in the second quarterly report.

Gas Permeability

Eight hundred grams of fly ash sample was weighed by using the electronic scale having 0.01 gram accuracy. Water was measured by graduated glass cylinder (30% of the fly ash sample). Fly ash and retarder (0.5%) were added in water while agitating the mixture in mixer. The procedure followed was according to Section 5 of API² Recommended Practice 10B. The fly ash slurry was cured in a 2 in. × 2 in. core holder for 7 days in water bath maintained at 80 °F and a 1 in. diameter fly ash specimen (Fig. 1) was cored. Prior to testing, the sample was dried to a constant weight in a drying oven.

The nitrogen gas permeability measurements are made using 1 in. diameter core samples and the Gas Permeameter, which is designed by the Well Construction Technology Center of the University of Oklahoma (Fig. 2). Tests were performed in accordance to Section 11 of API² RP 10B.



Figure 1 - 1 in. Cored OD Fly Ash Samples for the Permeability Test

The fly ash sample was placed in the Hassler Sleeve core holder assembly. Then, it was sealed in the permeameter by means of nitrogen gas confining pressure of 200 psi. The appropriate pressure was applied to the upstream side of the core sample using the pressure regulator to obtain the gas flow rate. Two measurements determine the permeability of the core sample: the pressure drop across the sample and the flow rate through the core. The pressure

drop across the core sample was given by the digital readout which was connected to the upstream and downstream pressure transducer. The flow rate through the core sample was obtained in cc/min when the gas flow rate was stabilized.

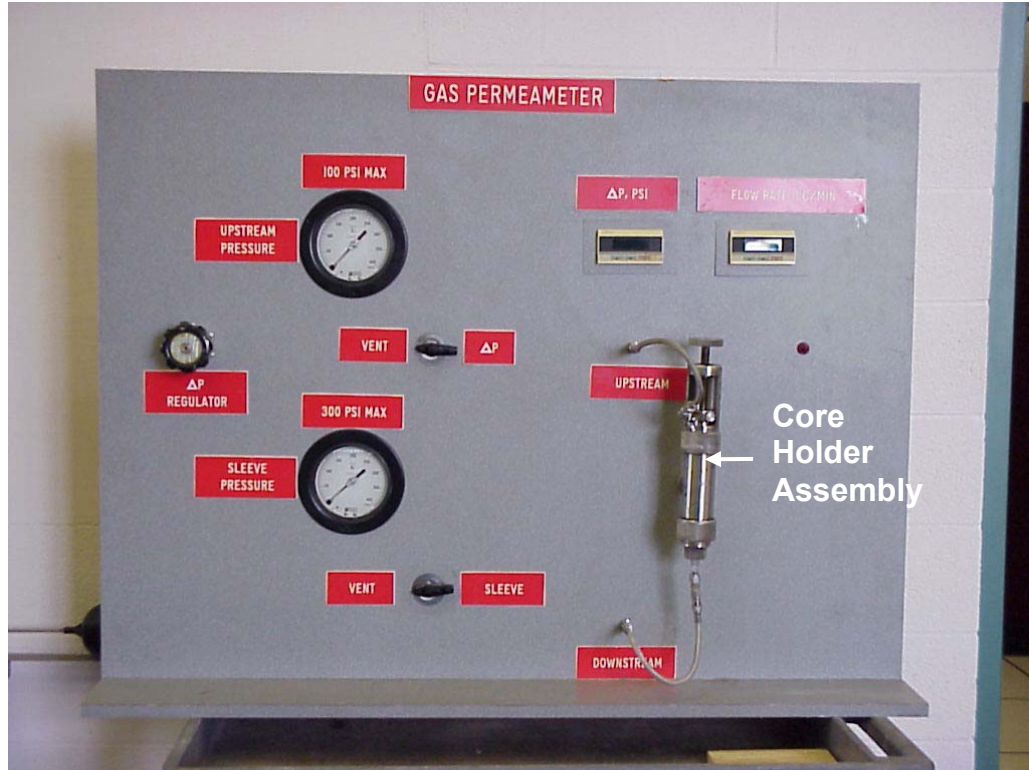


Figure 2 - Gas Permeameter at Well Construction Technology Center.

The viscosity of nitrogen gas used for calculation of permeability was 0.018 cp. The permeability was then calculated by the following equation.

$$k = \frac{2000 \times q \times p_0 \times \mu \times ds}{A \times (p_i^2 - p_o^2)}$$

where, k : permeability (md) q : flow rate (cc/sec)
 μ : viscosity (cp) ds : length of core sample (cm)
 A : cross sectional area (cm²) p_i : inlet pressure in atmospheres (psia/14.7)
 p_o : outlet pressure in atmospheres (usually 1 atm)

Cements that are set for 3 to 7 days have a gas permeability of less than 0.1 md. Dolomite and limestone have an average of 2 to 3 md and the gas permeability of sandstone⁶ ranges from 0.1 to 2,000 md. The gas permeability of fly ash core ranged from 0.006 to 0.52 md as shown in Table 3. All fly ash samples exhibit significantly lower permeability and they are of the same order of magnitude on Class H cement⁵. The Muskogee sample showed the lowest permeability

of 0.062 md. As a result, it is evident that the gas migration through fly ash plug in the wellbore, if any, will be at minimal.

Table 3 - The Permeability of Fly Ash Samples and Class H Cement Sample

Item	Oologah	Muskogee	Hugo	Oklaunion	Red Rock	Class H cement
Permeability, md	0.521	0.062	0.262	0.241	0.237	0.197

References

1. Ormsby, G.S., Grace, R.D., Patton, C.C., and Smith, D.K.: Drilling Practices Manual, The Petroleum Publishing Co., Tulsa, p. 400-446, 1974.
2. American Petroleum Institute Recommended Practice 10B, 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.
3. American Petroleum Institute Recommended Practice 10A, 22nd Edition, American Petroleum Institute, Washington, D.C., January 1995.
4. Cementing Technology, Dowell Schlumberger, Nova Communication Ltd, London, 1984.
5. Nelson, E. B.: Well Cementing, Schlumberger Educational Services, Netherlands, 1990.
6. Smith, D. K.: Cementing, SPE Monograph, vol. 4, Society of Petroleum Engineers, Dallas, 1976.

Publications/Presentations

1. Shah, S.N., and Jeong, Y.T.: “The Flow Characteristics of Fly Ash Slurry for Plugging Abandoned Wells Using Coiled Tubing”, 2003 International Ash Utilization Symposium, Lexington, KY, Oct. 20-22, 2003.
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

Field tests will be performed to verify the appropriateness of an environmentally friendly fly ash plugging technique developed in this project. Two test wells will be selected by Oklahoma Corporation Commission (OCC) and will be plugged by Acidizing and Cementing Services of Oklahoma (ACS) using the optimum fly ash formulation developed in previous project.