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The road to a cement alternative for plug & abandonment of low temperature wells in West Texas

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Abstract

API approved cements are the current product of choice for plug and abandonment in Texas. The shortcomings of Portland cement as a P&A material have been well documented in literature. Tight supply, increasing cost and high carbon footprint are further incentives to develop alternative P&A solutions. Alkali activated aluminosilicate alternatives have the potential to be a sustainable green material at an equivalent or lower cost, with other performance benefits over the standard cement systems.

This paper describes the steps taken to formulate a cement alternative for P&A of low temperature wells in the Permian Basin. A suitable blend was developed using a local source of class F fly ash, having only a moderate level of powder alkali silicate as the activator. The resulting material had lower viscosity and longer thickening times than conventional cement. Material properties were extensively tested and included small gap penetration between two parallel plates.

The path to be a plug and abandonment material involved first demonstrating the alkali-activated aluminosilicate as a sealing material for water shut-off and casing repair. The first field trials involved treating old wells that had reached the point where they were only producing water from the San Andres reservoir. These trials allowed for refinement of mixing and pumping strategies as well as remediation of excess water production. Further iterations in the formulation and placement technique will improve effectiveness as a conformance treatment and help qualify alkali-activated aluminosilicates as a suitable P&A material.

Introduction

Ordinary Portland Cement (OPC) is the principal material used to for zonal isolation as well as to protect and seal the wellbore. This covers sealing between casing and formation, remediation, lost circulation, conformance and finally plug and abandonment. Cement is a wonder material but there is growing recognition that OPC might not be the best material for all types of zonal isolation. The deficiencies of OPC for zonal isolation are summarized by (Kalifeh et al., 2016; Salehi et al., 2017; van Oort et al., 2019);

- poor adhesion to casing
- brittle
- damaged by oil-based mud
- does not self-heal
- subject to acid attack
- prone to shrinkage
- high carbon footprint

These deficiencies are most acute in P&A applications where there is a need to a material that can stand the test of time. Emerging, as a strong contender as an OPC substitute are Alkali Activated Materials (AAMs) with geopolymers as a subset. Given the potential of AAM there is a growing body of work to show their viability for zonal isolation. A leader in this field is the University of Texas at Austin through it's industry-affiliate consortium (i.e. CODA). The consortium has been in existence for 5 years and is dedicated to finding technical superior alternatives for well construction, decommissioning and abandonment work. The University of Stavanger is another leader that is also developing a geopolymer-based material for P&A (Khalifeh M., et al., 2015) These institutes have extensively investigated the chemistry, formulation, slurry and material properties of alkali activated materials/geopolymers.

Despite very convincing lab data, AAS material has made minimal in-roads for plug and abandonment. The lack of adoption can be partially attributed to lack of regulatory approval and the high risk associated with using a new material for something as critical and expensive as plug and abandonment.

Outside of P&A, there has been some activity in using AAM for cement remediation, conformance and LCM applications but the technology would be considered in the trial/early commercialization stage. Factors contributing to the slow rate of pick-up include;

- typically more costly vs. OPC
- handling challenges associated with high pH
- often needs to be formulated on-site
- more temperamental than OPC
- variations in aluminosilicate material

- lack of admixtures

This paper describes how the above challenges were addressed while solving the costly problems of casing repair and water shutoff. Success in these applications was deemed a necessary step to de-risk their use in P&A.

Fit for Purpose

To help address the shortcomings associated with AAMs, product development targeted a specific region and well type. This fit for purpose approach would then formulate with a local and readily available materials. With this in mind, development efforts were focused on a product that could remediate casing leaks, seal microfractures, narrow channels and micro annuli in the cement and the formation. The target well type would be low temperature, vertical wells in the Permian Basin.

In West Texas, it is not unusual for operators to perform some of their own conformance treatments. For an operator looking to DIY a conformance treatment, the feedback was a cement alternative should look like cement but have the following improvements/ characteristics;

- Just add water product
- Longer thickening time of 5 to 6 hrs at 110F
- Higher tensile strength
- Less prone to shrinkage
- Smaller particle size
- Similar or lower cost

It might appear overtly specialized to develop an AAM for use in low temperature wells in West Texas but casing leaks, cement remediation and water shutoff are universal and costly problems. Further, the developed product can be easily modified for use in medium or higher temperature wells. Learning from the Permian Basin would be transferrable to other regions. These older, vertical wells would also be prime candidates for moving to plug and abandonment.

Materials

The making of an alkaline activated material involves mixing an aluminosilicate source that is an amorphous powder into an alkaline solution. Potential starting materials are their roles are summarized in table 1.

Table 1: Potential Precursor Materials

aluminosilicate	• waste products (e.g. fly ash, blast furnace slag, tailings) • natural products (e.g. pumice, zeolite, kaolin clay, rice husk ash) structure and composition dictate reactivity and material properties
Alkaline activator	• sodium and/or potassium silicate • sodium and/or potassium hydroxide silicates and hydroxides are often used in combination
Admixtures	• Dispersants • Retarders • accelerators • gas generating additives • fluid loss additives

Class F fly ash was the default choice for aluminosilicate material. It has been extensively studied and shown to make an effective alkali activated material (Horan et al., 2022). It is readily available in Texas and looks to remain available for the foreseeable future. Two sources of Texas class F fly ash were investigated as potential starting material. Table 2 shows the typical oxide content.

Table 2: Class F fly ash from Texas

	"A"	"B"
Oxide	Wt (%)	Wt (%)
SiO_2	62.84	54.80
Al_2O_3	21.18	21.46
Fe_2O_3	2.38	4.77
$(SiO_2+Al_2O_3+Fe_2O_3)$	86.40	81.03
CaO	4.75	11.71
MgO	0.65	2.39
Na_2O	3.83	0.33
K_2O	2.22	0.98
(Na2O+ 0.658K2O)	5.29	0.97
Moisture	0.06	0.07
LOI	0.47	0.36

Alkali activators are usually some combination of sodium hydroxide, potassium hydroxide, sodium silicate and/or potassium silicate. The choice of alkali will have an impact on viscosity, thickening time and compressive strengths. The selection of activators can be exploited to yield desired results for downhole temperature and pressure conditions (van Oort et al. 2019). For ease of use, the focus was on alkali activators available as a dry free flowing powder. Table 3 provides a summary of the candidate grades of alkali silicate. Sodium and potassium hydroxide are also available in a solid form. However, the decision was made to formulate with aqueous products for the initial trials. This decision was based on limited blending capabilities and the need to have proper packaging to prevent excess moisture pick-up. Anotherconsideration was an increase exotherm with sodium/potassium hydroxide going into solution.

Table 3

	Wt% Na_2O	Wt% SiO_2	Wt% Water	Ratio SiO_2: Na_2O
GD®	27.0	54.0	18	2.0
Kasolv® 16	32.5 (K_2O)	52.8	14.7	1.6
Metso® 2048	51.3	47.6	<2%	1.0
Metso® pentabead	29.3	28.4	41.3	1.0

A cursory evaluation was done on admixtures in the form of retardants and dispersants. The use of these products were deemed unnecessary for lower temperature application. Testing showed the desired thickening time could be achieved by careful selection of alkali activator type and using a specific water to solids ratio. Testing also showed the viscosity of the AAM slurry was less than the OPC control. As a side note, powder silicate have a high absorption capacity for liquids (McDonald et al., 2014). If liquid admixtures were to be incorporated into a ready to use product then the plan was to use the powder silicates as a carrier.

Experimental

Formulation and testing protocols were based on past work by University of Texas at Austin through the CODA program. This provided a starting point for ratios of;

- Water to solids
- Silica to alkali
- Alkali silicate to alkali hydroxide
- Alkali to fly ash

Preliminary screening experiments on viscosity and compressive strength showed that of the two Texas-based sources of class F fly ash, the fly ash indicated in column 2 of table 1 provided lower viscosity with higher 24 hr compressive strength (i.e. >500psi). The higher early strength was in part related to the higher level of CaO that would also allow for the formation of hydration products.

Special attention was paid to water to solids ratio as this controls viscosity, thickening time and compressive strength. For the selected fly ash, all mix designs could meet the requirement of 500 psi compressive strength at 24hrs. with a water to solids range of 0.30 to 0.36

Prior work has shown potassium hydroxide and/or potassium silicate gave the longest thickening times and lowest viscosity (van Oort et al., 2019). For the target low temperature environment, the use of a combination potassium hydroxide/spray dried potassium silicate resulted in an excessively long thickening time of ~12 hrs @ 110°F. The move to potassium hydroxide/spray dried sodium silicate resulted in a thickening time of just under 6 hrs @ 110°F. The control was class C cement that was made to a water to solids ratio of 0.4. Compared to the AAM, the OPC control had a higher viscosity.

Alkali activated material as an alternate to microfine

The selected class F fly ash particle size had a d70 of 45micron which is close to the same particle size as class C cement Aluminosilicate particle size is a starting indicator on penetrability. The alkali activation process leads to attack of the particle surface which results in partial dissolution and reduction in particle size (Salehi et al., 2016). It was hypothesized the AAM should have better penetration into pinholes, microannuli and narrow channels and be more in line with microfine cement vs. conventional oilfield cement. A parallel plate test (figure 1) had the AAM slurry and OPC slurry injected at a constant flow rate between two plates separated by distance of 125 microns. Penetration was measured by distance of slurry travel and pressure needed to inject the slurry. Compared to the OPC control the selected AAM was injected with 25% less pressure and went nearly 2x further.

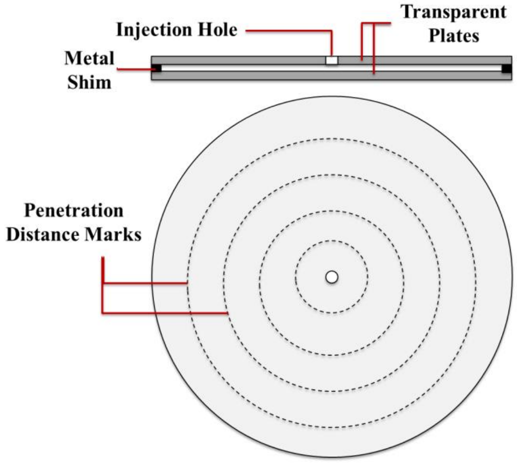

Figure 1: Set-up to measure penetrability

Initial field trial

The operator had multiple wells that were producing excess water. These wells shared the characteristics of being drilling in the 1950's & 1960's and producing from the San Andres reservoir. All were candidates for geopolymer treatment with final choice being a relatively recent hydraulically fractured well that had started to pick-up water through the fracture network. The treatment was estimated at ~100 bags of cement for a volume of 132 ft^3 . This was calculated to be significantly less material compared to most other candidates. The well had good diagnostics allowing for a better understanding of the location of the water pathways. The trial objectives were set out as;

- Demonstrate that AAM can be safely and effectively made on location
- Reduce water production by 30%
- Compare performance of AAM against offsets

having used cement

As an alternative to using a batch cement mixer, the preparation and pumping would be done using an acid pump truck and a circulating tank (figure 1). The use of an acid pump truck would provide more than sufficient pumping capacity for mixing and placing the AAM at a significantly lower cost.

The trial involved diluting 45% ppotassium hydroxide with fresh water to the desired concentration. The system was set-up in a loop for safety and to provide the necessary mix conditions. Fly ash would be added to an auger bin (figure 2) and would be added be to circulating activator solution. For this trial, the spraydried sodium silicate was not blended into the fly ash but would be added after the addition of fly ash.

Process control was done by catching and testing sample material. A mud balance was used to ensure the mix had the desired density. This was a simple but effective method to ensure the mix was at the desired water to solids ratio. Less critical was viscosity that was measured on location using an OFITE viscometer. Retain samples were kept for compressive strength testing

The scale-up from lab to field provided several learnings related to volume, mixing and exotherm. As a first time effort, the rate of addition of dry components to the activation solution took just over two hours. The lengthy rate of addition was related to unfamiliarity with the system and the outside of the box mixing procedure. While the long rate of addition was not ideal, there should been sufficient time for pumping and placement. This led to the second lesson learned that related to exotherm. Lab studies showed that upon mixing of solid material into the diluted alkali solution, the exotherm broughtthe mix from room temperature to ~130°F. The lab material would then be quickly cooled to 110°F to measure viscosity and thickening time. In contrast, the trial took place in August with an outside temperature of ~100°F. The exotherm took the mix to 142°F and the large volume and high outside temperature meant minimal cooling of the slurry. The exotherm also resulted in significant water evaporation as observed in the density readings. Water was required to bring the density to the desired solids level. The result was at ~3hrs the mixture was beginning to show signs of thickening. At this point, the density readings were beginning to drop indicating there was some settling of AAM in the circulating tank. The decision was made to begin pumping (figure 3), of the 26 bbl of material only ~8 bbl were pumped before the decision was made to halt pumping because of thickening issues. Cleaning out the recirculation tank, it was confirmed there were issues with product settling in the back corners of the circulation tank. Retain samples of the geopolymer were tested at 3 days after aging at RT and were shown to have a compressive strength of 993 psi.

The impact on water production was inconclusive and it was deemed there was insufficient volume to have a real, long term impact on water production.

Fig. 1: Circulating tank

Fig. 2: preparation of AAM material

Fig. 3: placement of AAM material

Yard trial

For the next trial, mixing would be done using a 1 yd3 cement mixer and placement would be done using a using a small pump owned by the operator. Based on experience from the first trial, it was decided to first run a small yard trial to verify mixing time. To accomondate the volume of the cement mixer, blends were made using a 1000 lbs of fly ash (i.e. ½ a super sack). This yield approximately ~ 15ft3 of material when blended with other components .

The diluted KOH solution was carefully added the cement mixer. Fly ash/silicate was then augured into the cement mixer (figure 4). The addition of fly ash and silicate took <3 minutes. The fly ash and sodium silicate powder easily blended into the diluted alkali solution and was thoroughly mixed in under to minutes. Mixing would be described as low shear conditions.

Samples were taken for initial and final viscosity. AAM material was used to fill a large pot hole (figure 5). Upon poring, the filled pothole showed a homogenous material that had no signs of lumps and/or agglomeration. The filled pothole was in a high traffic area and allowed for continuous observation of durability and aging. After a year there were some weathering of the surface but showed minimal cracking.

Fig. 4: dry components being mixed into activating solution

Fig. 5: AAM after ~24hr

Trial #2

The next well was producing 100% water from below the wellbore. Casing testing indicated injection San Andres reservoir. The well had under gone a polymer treatment approximately 7 years ago which resulted in an extremely short reduction in water production. Prior to running the AAM treatment the operator a pressure test and found an extremely low injection rate. The low injection rate was attributed to a build-up fines around the well bore that was acting a check valve. The AAM treatment was pushed back to allow for the clean out of fines. After cleaning the injection rate was 1 bbl/min at 250 psi Treatment was sized similar to the yard trial at ~15ft3 batches (figure 6). Similar to the first trial, density was used as the process control. The material was pumped without a spacer and displaced with 25 bbl of water. All of the AAM went into the formation and the injection pressure began to rise to 600 psi. After re-establishing production, water production was close to 100% but rod pump suggested the water was coming from the production casing annulus (note: there were no casing leaks). Water analysis indicated relatively fresh with Cl <20 000 mg/l . Operator will try using a packer to isolate the upper source of water. Failing this, another AAM treatment will be run.

Fig. 6: preparation of slurry for pumping

Conclusions

A fit for purpose alkali activate material was developed for low temperature wells in West Texas for casing repair and water shutoff applications. Lab and field results showed;

- Developed formulation met the requirements for longer set times, lower viscosity, improved ductility and more tolerant to oil contamination
- Mixing and pumping techniques are still a work in progress but initial results show the rheology and thickening times lend themselves to the use of readily available and cost effective equipment
- The material cost of the AAM is estimated to be close to the midway point between OPC and microfine cement. Penetration tests indicate that performance would be more in line with microfine cement.
- Base formulation could be easily modified for higher temperature wells
- Proper handling and PPE is required for the high pH environment necessary to activate the fly ash
- Learnings are transferrable to other regions
- Success with water control and casing repair will provide confidence to operators and regulators to allow the use for plug & abandonment

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Nomenclature

Define symbols used in the text here unless they are explained in the body of the text. Use units where appropriate.

AAM = Alkali Activated Material
bbl = barrel
OPC = Ordinary Portland Cement
P&A = Plug and Abandonment

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