Development of an Environmentally Friendly and Economical Material for Plugging Abandoned Wells

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Objectives

- To verify that the use of fly ash instead of cement in the plugging of abandoned oil, gas, and water wells
- To develop the optimum grout formulation for plugging material in order to provide a cheaper, environmentally friendly, and more economical method of plugging wells

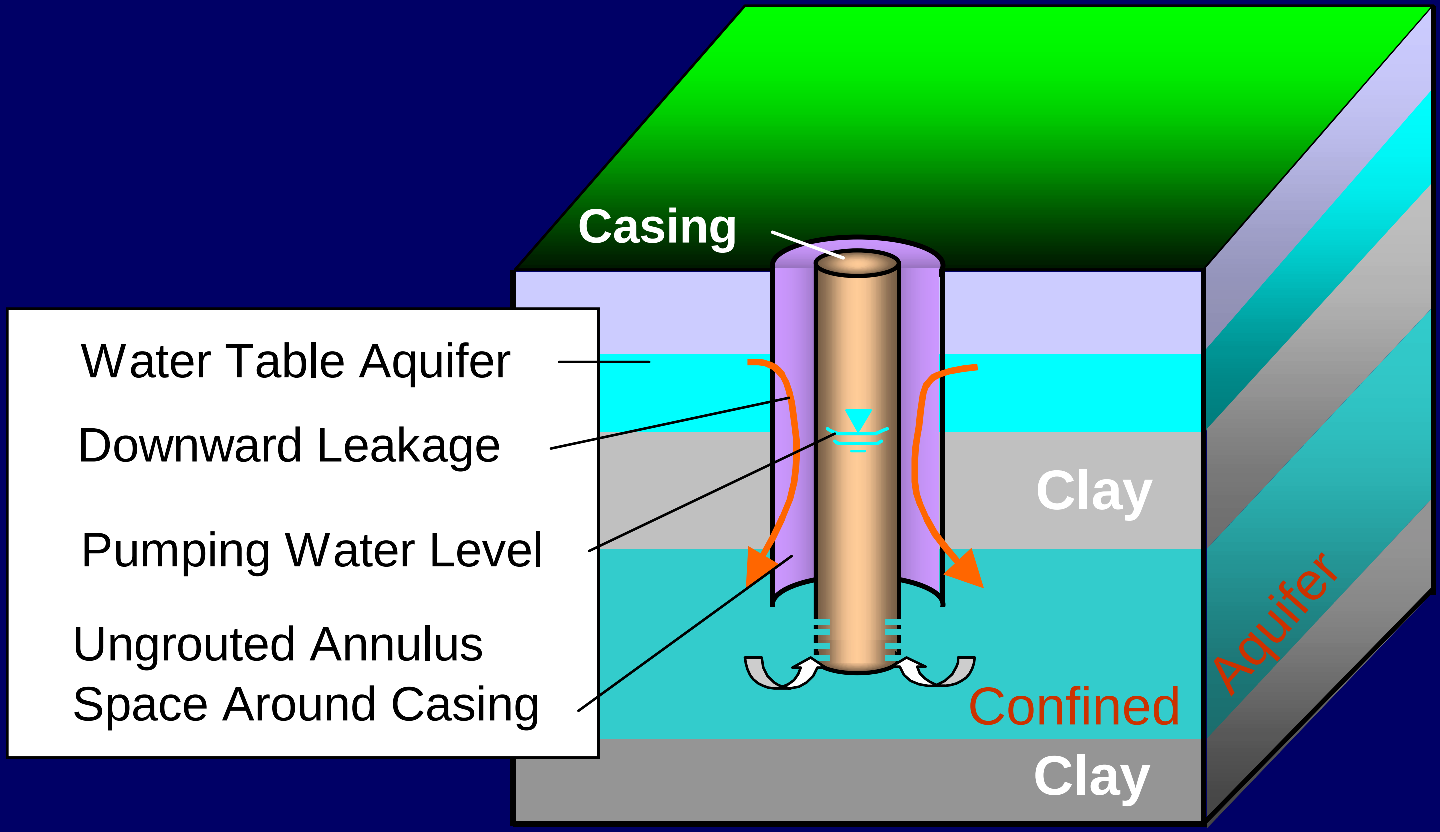
Introduction

- An average of 6,370 oil, gas, and dry holes were drilled in Oklahoma each year with an average depth of 5,051 ft (1980-1991)
- Water well construction in Oklahoma has averaged 3,042 per year (since 1985)
- Plugging and abandonment may include several cement plugs
- Fly ash is known to have properties very similar to cement and can be produced with strength similar to cement
- Fly ash does not have any harmful material among its components

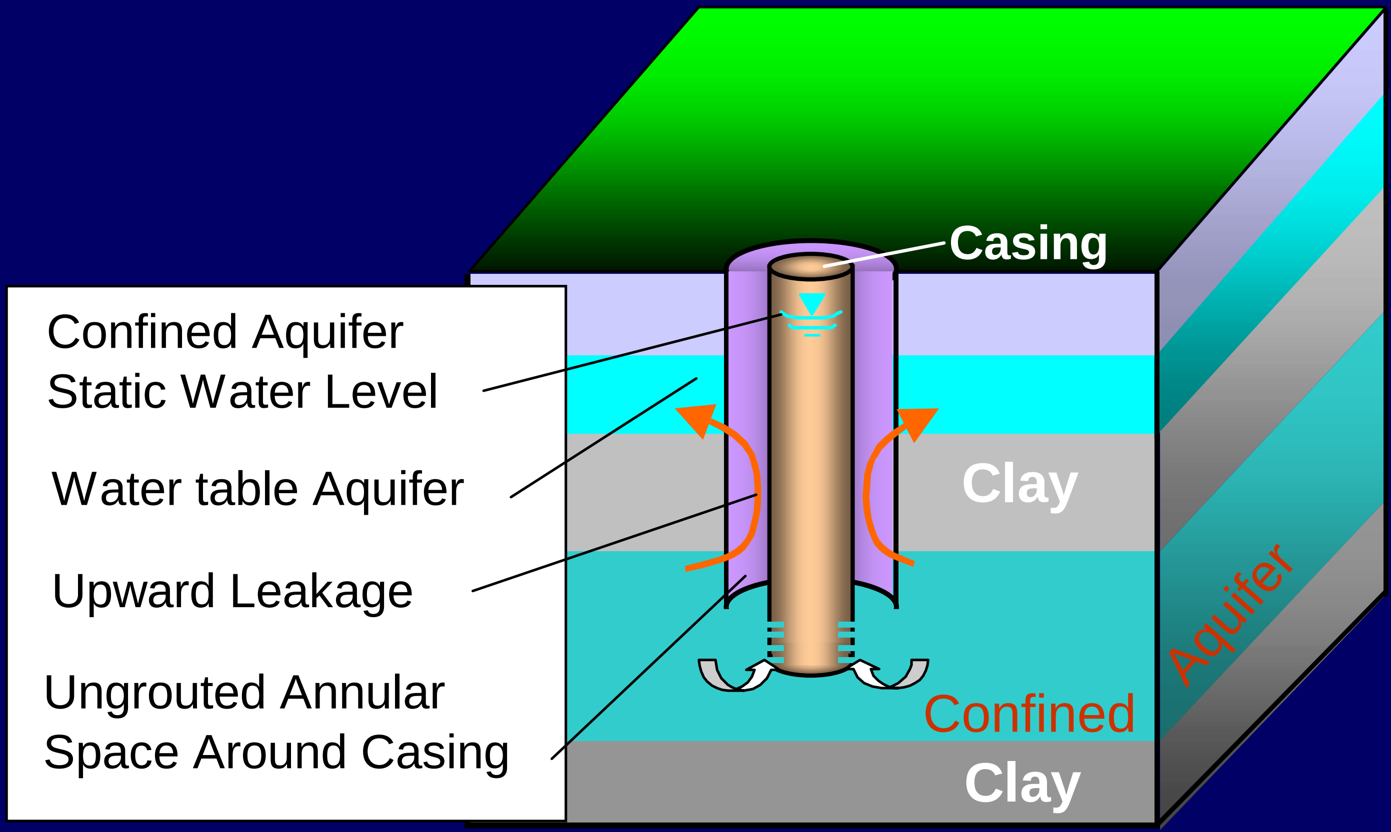
Why is Plugging Important?

- Unused and improperly abandoned wells can become a significant threat to groundwater quality - directly channel contaminated surface or soil water into freshwater aquifers
- It can become a source of pollution, contamination, and loss of groundwater

Downward Leakage



Upward Leakage



Research Methodology

Fly Ash Characterization

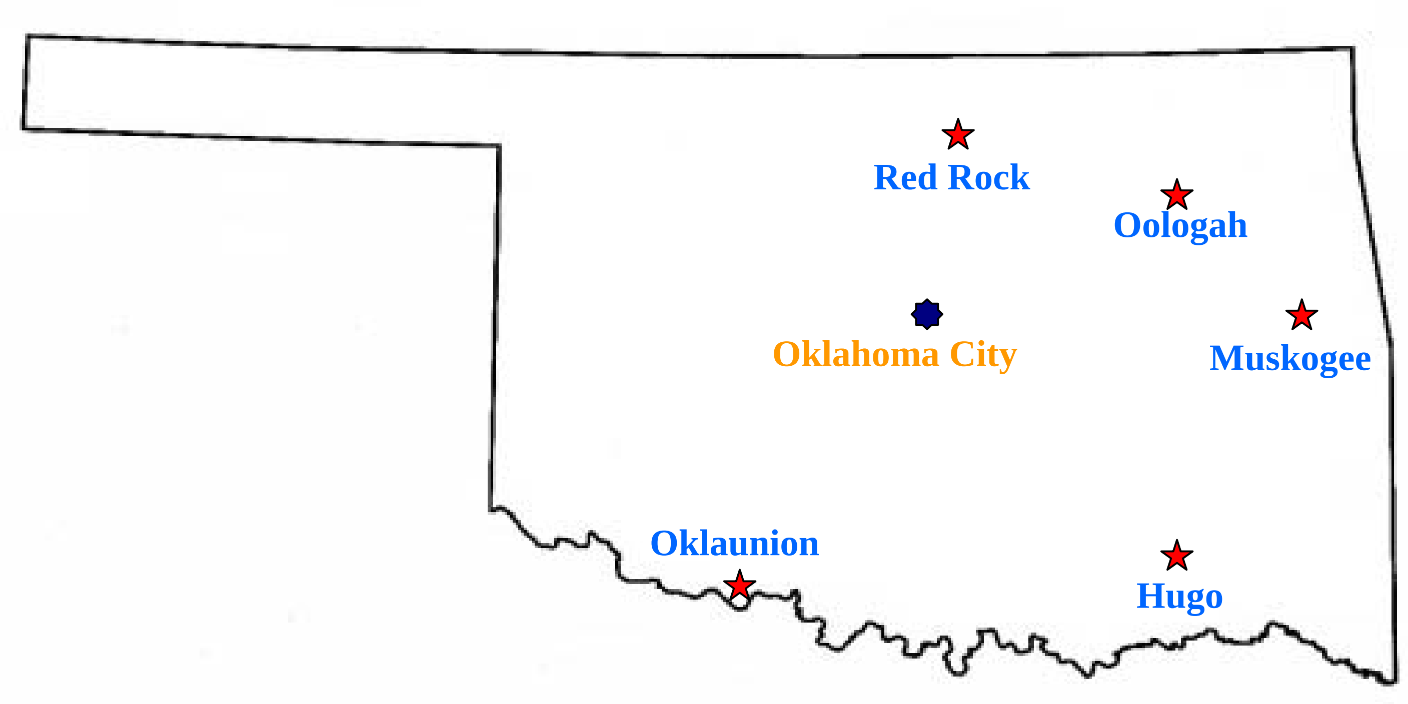
Fly Ash Grout Formulation

Physical Property Tests

Coiled Tubing Pumpability Test

Optimum Plug Material

Fly Ash Sources



These five major power plants using the same Wyoming coal as fuel and produce over 90% of fly ash in Oklahoma

Particle Size Distribution

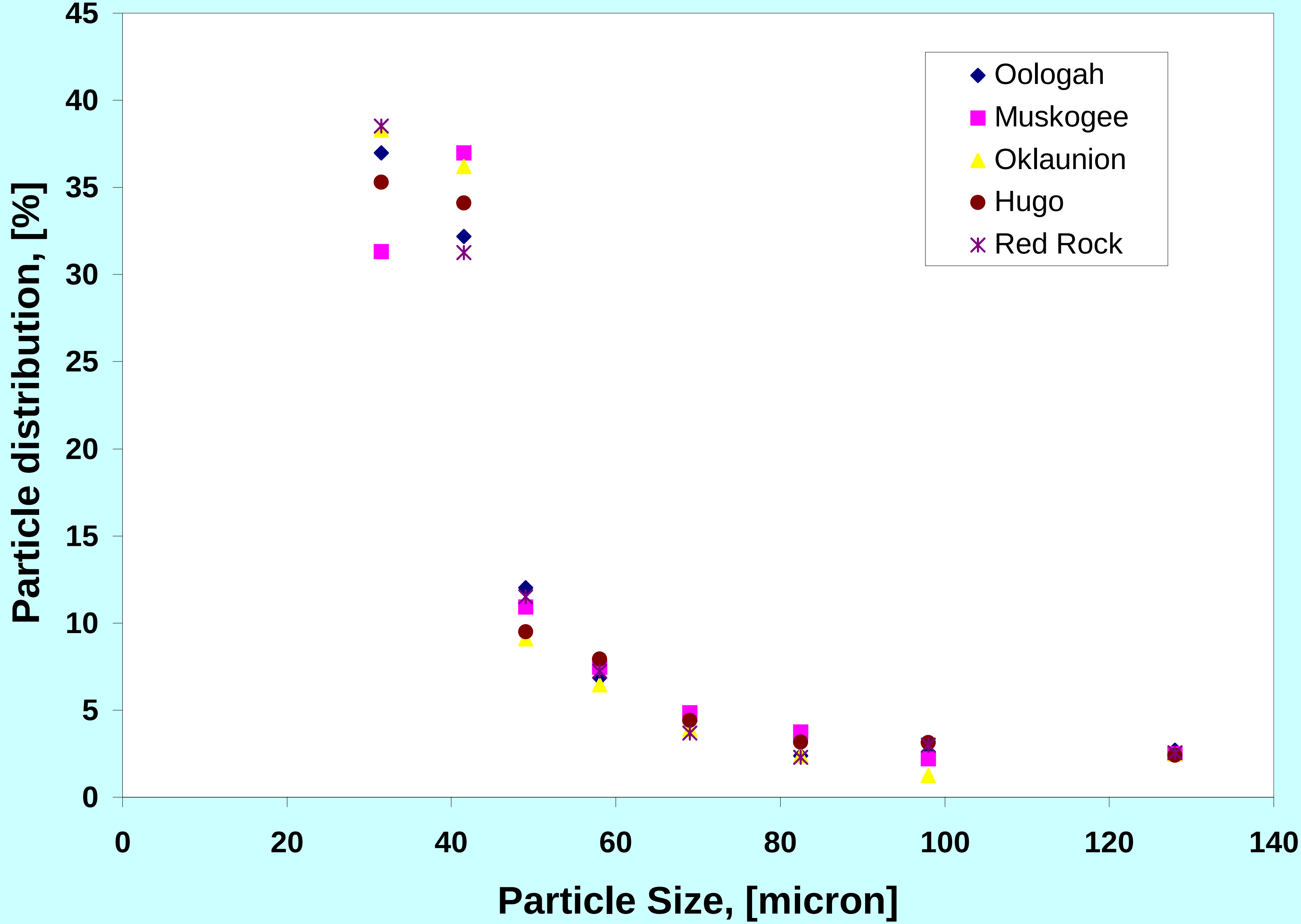
- Criteria: ASTM C 136 – Sieve Analysis of Fine and Coarse Aggregates
- Assumption: grains are spherical
- Surface area

$$\frac{Surface\ Area\ of\ a\ Sphere}{Volume\ of\ a\ Sphere} = \frac{\pi d^2}{\pi d^3/6} = \frac{6}{d}$$

$$A_s = \sum \frac{weight\ on\ i^{th}\ screen}{density\ of\ fly\ ash} \times \frac{6}{d_i} \quad (ft^2)$$

Particle Size Distribution

Source	Oologah	Muskogee	Oklaunion	Hugo	Red Rock
Desnity (g_m/cm^3)	**2.65**	**2.68**	**2.74**	**2.71**	**2.63**
Surface area (ft^2/lb_m)	**270.72**	**261.40**	**267.11**	**261.99**	**274.34**



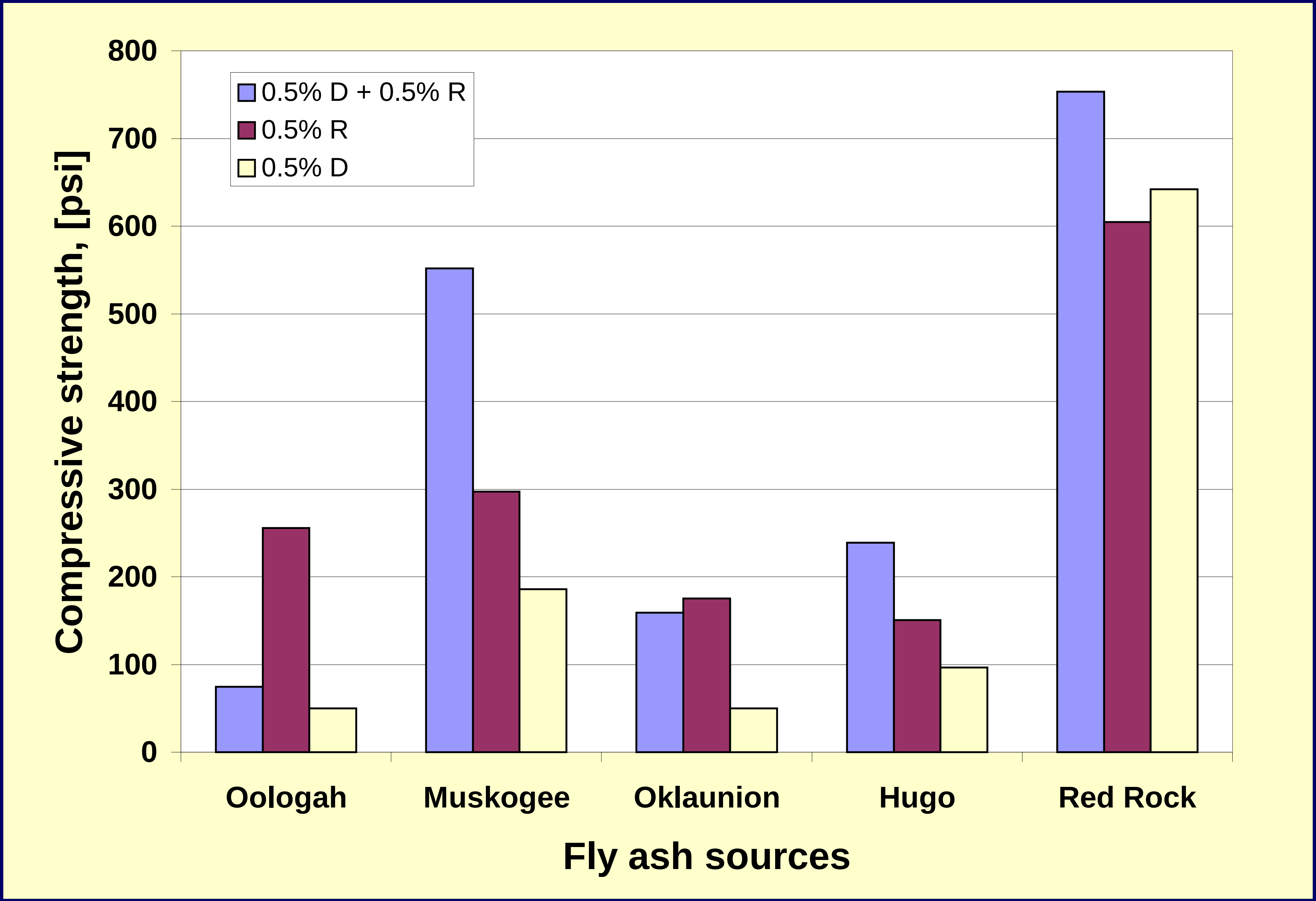
Particle size distribution

Chemical Analysis Results

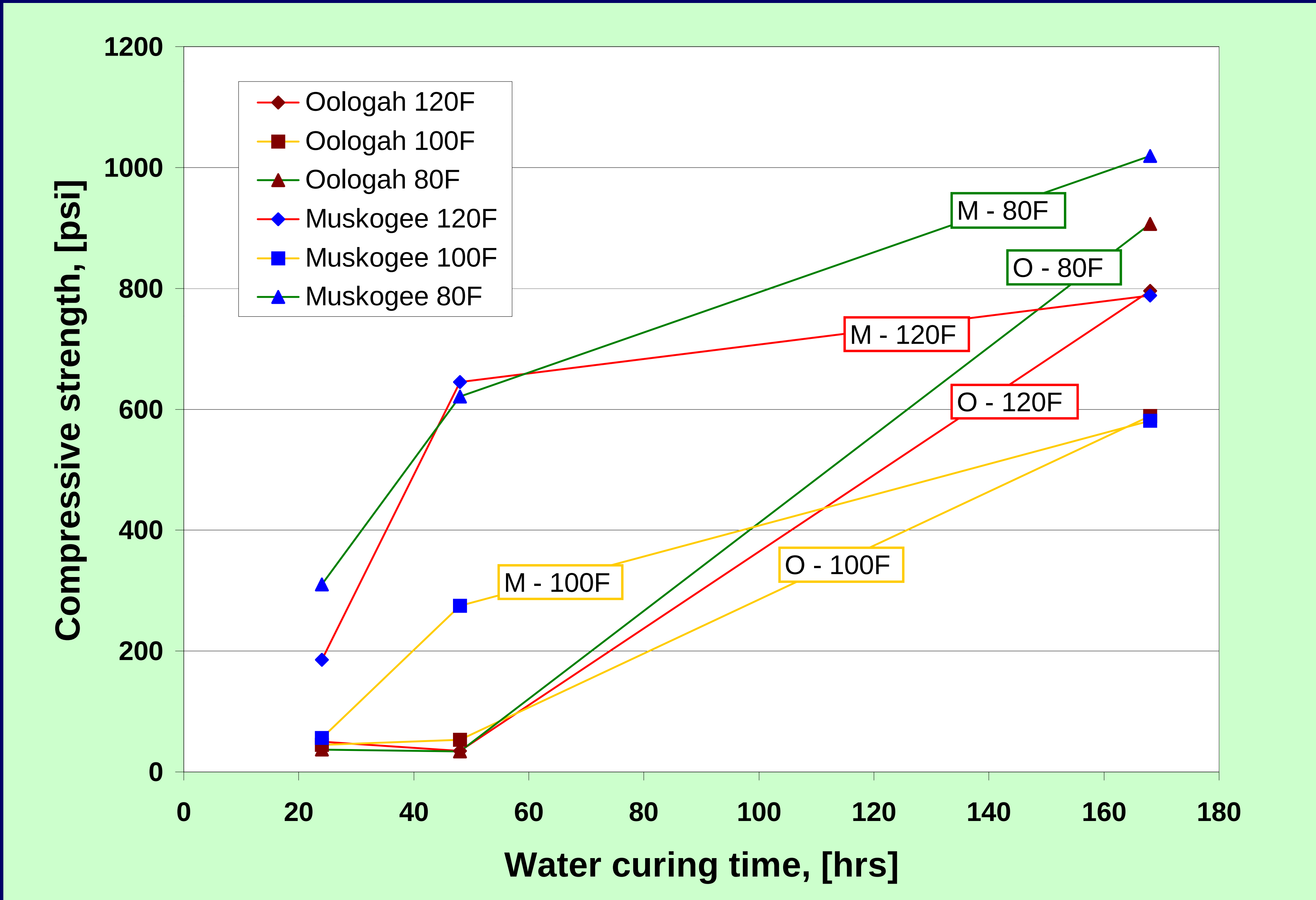
Items	ASTM C-618 Class C Requirement	Oolo-gah	Musk-ogee	Hugo	Okla-Union	Red Rock
Silicon dioxide (SiO_2)	-	33.04	33.48	33.60	36.70	34.87
Aluminum oxide (Al_2O_3)	-	22.97	22.34	19.52	18.57	22.96
Iron oxide (Fe_2O_3)	-	5.41	5.28	6.09	6.00	5.29
Sum of SiO_2, Al_2O_3, and FeO_3	50.0 min	61.43	61.09	59.21	61.07	63.12
Sulfur trioxide (SO_3)	5.0 max	1.41	2.04	3.53	1.70	1.43
Calcium oxide (CaO)	-	26.58	26.72	27.32	25.83	25.04
Magnesium oxide* (MgO)	-	6.02	5.75	6.08	5.97	5.75
Available alkalies* as Na_2O	1.5 max	1.44	1.42	-	1.03	1.32

Physical Analysis Results

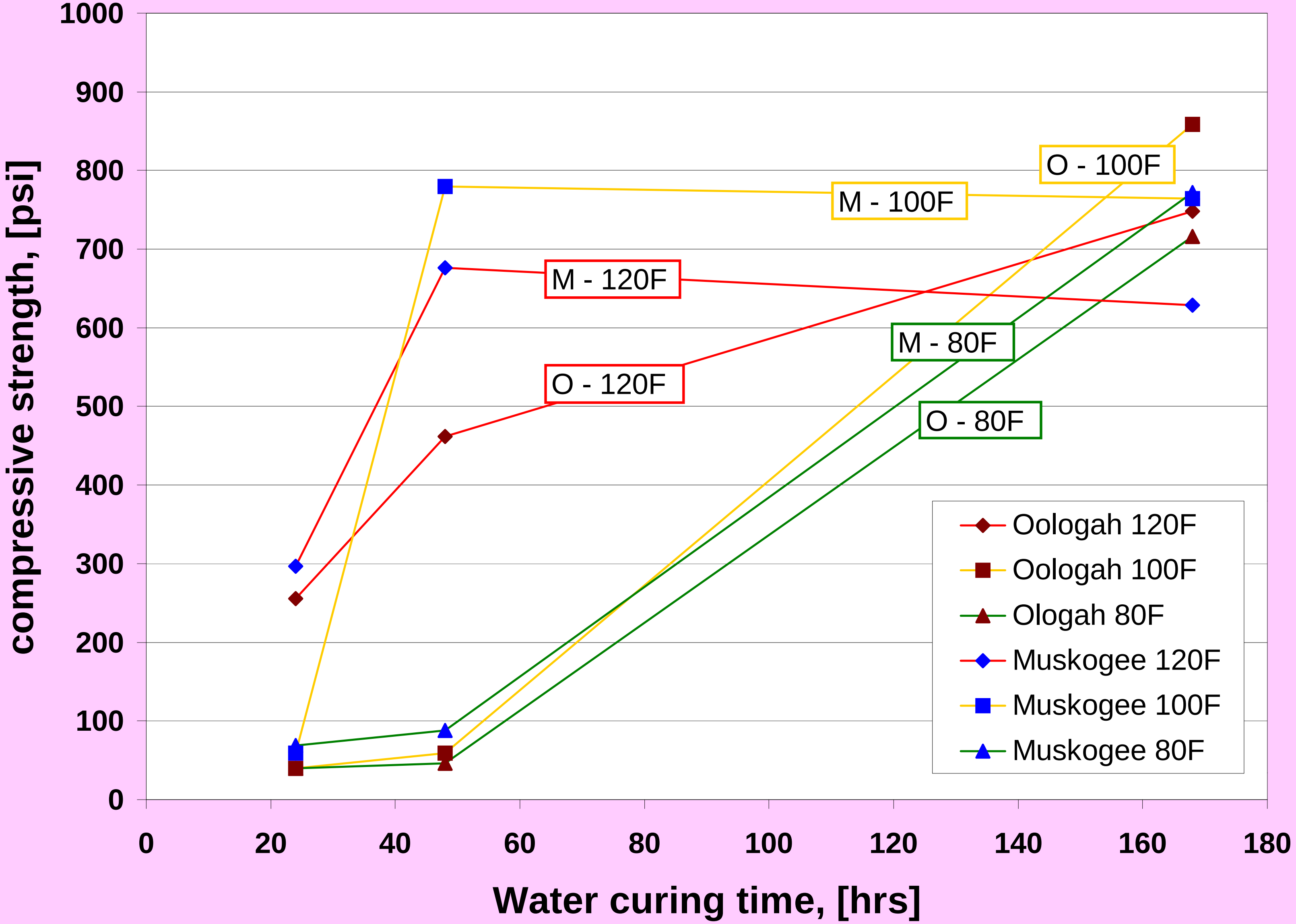
Items	ASTM C-618 Class C Requirements	Oologah	Musko -gee	Hugo	Okla Union	Red Rock
Finess (+325 mesh)	34.0 max	15.14	14.69	19.90	13.90	15.57
Finess variable	5.0 max	-	0.45	1.10	-	0.53
Moisture content	3.0 max	0.08	0.10	0.14	0.07	0.06
Specific gravity	-	2.65	2.68	2.74	2.71	2.63
Specific gravity variable	5.0 max	-	0.32	1.87	-	0.38
Loss on ignition	6.0 max	0.18	0.25	0.28	0.20	0.27
Autoclave expansion	0.8 max	0.03	0.03	0.05	0.02	0.01
Water require % control	105.0 max	93.53	93.50	96.63	90.90	93.53
SAI 28 days	75.0 min	97.78	97.59	94.43	106.43	98.60



Compressive strength test with 24 hours water curing at 120 ºF



Effects of 0.5 % dispersant on compressive strength



Effects of 0.5 % retarder on compressive strength

Thickening Time

(Unit: hrs)

Fly Ash Source	0.5 % D	0.5 % R	0.5% D + 0.5 % R
Oologah	0:15	1:50	4:00+
Muskogee	0:15	2:02	4:00+

Note: D and R represent dispersant and retarder, respectively

To determine the duration a given fly ash slurry remains as a pumpable fluid (atmospheric consistometer: the time of consistency reaches 100 B_c)

Product Durability Test

- To verify that the mean saturation coefficient of fly ash sources is insignificantly different from that of Portland cement

- Fluids: API brine and acidified water (pH≅5.5)

- Test Procedure:

  one week water curing⟶ one week drying⟶ immersing samples⟶ measuring weight increase

- Data analysis: ANOVA, Tukey tests

- Saturation coefficient

$$S_c = \left(\frac{W_w - W_d}{W_d} \right) * 100$$

W_w: wet sample weight

W_d: dry sample weight

Saturation Coefficient of Test Samples

(Unit: %)

Samples	Brine water	Acidified water
Oologah	9.62, 11.98, 9.56	8.76, 9.65, 11.54
Muskogee	10.17, 10.21, 11.13	10.21, 9.33, 9.52
Red Rock	8.81, 8.94, 9.05	8.76, 7.76, 7.91
H cement	8.46, 9.48, 8.75	8.76, 8.78, 9.31

Results of Multiple Tukey Tests

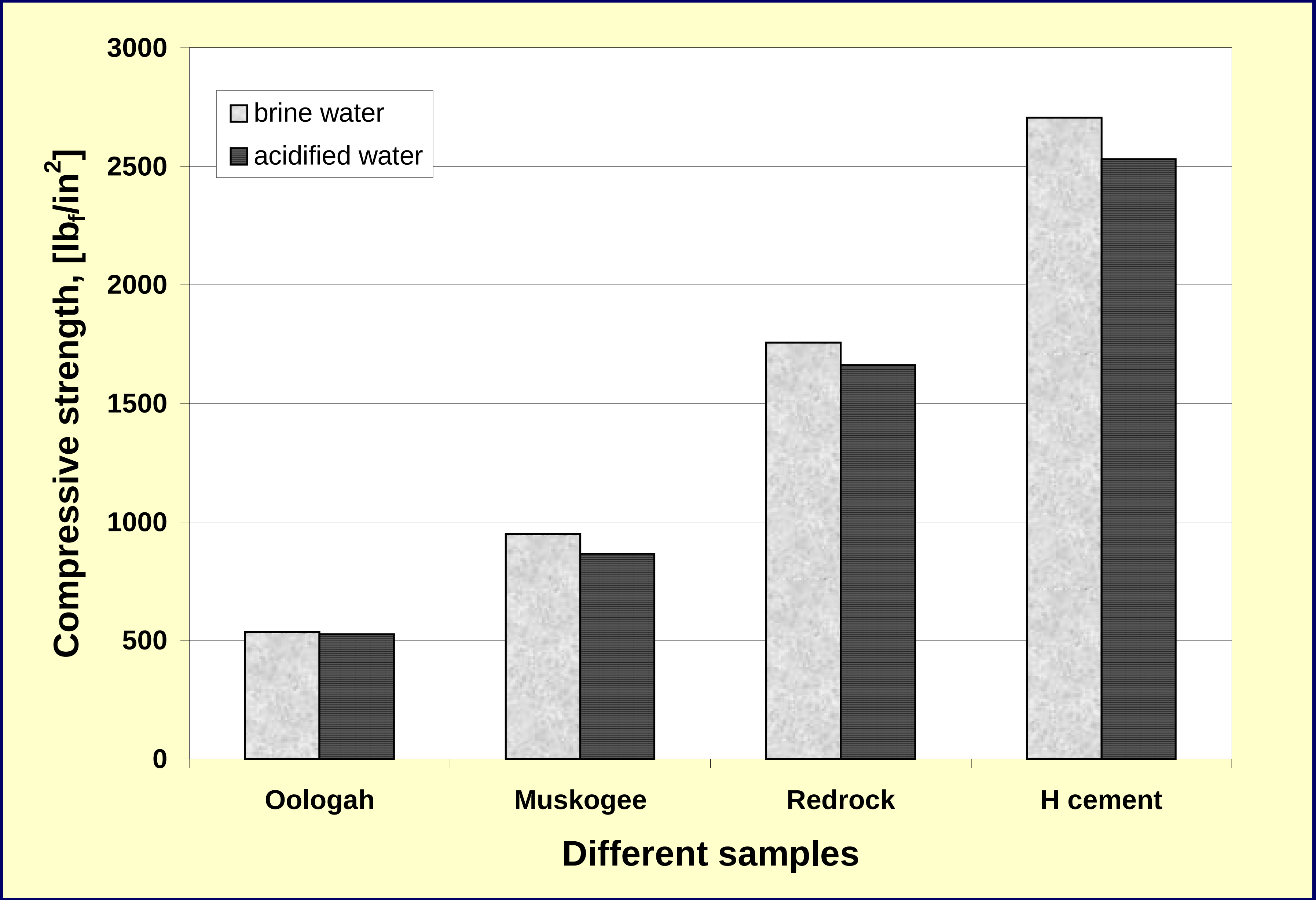
(Unit: %)

Samples	API brine		Acidified water	
	Mean	Tukey Group	Mean	Tukey Group
Oologah	10.387	A	9.983	B
Muskogee	10.503	A	9.687	B
Red Rock	8.800	A	8.143	B
H Cement	8.897	A	8.950	B

Significant level: 0.05

Compressive Strength Test After Durability Tests

- To verify that the strengths of fly ash samples were over 500 psi under the extreme conditions (API brine and acidified water)
- Test Standard: API Spec 10
- Samples: the same samples used for durability tests



Compressive strength after durability test

Fluid Loss Test

Time	Oologah	Muskogee	Oklaunion	Hugo	Red Rock
15 sec.	4.5	5.3	3.5	5	6
30 sec.	6.5	7.0	6	8.5	10.8
1 min.	10	10.5	10.3	14.5	17.5
2 min.	14.8	18.5	18	24.2	29
5 min.	2	36	39.2	48.8	50
7.5 min.	33.8	47.5	54	65.2	56
30 min.*	67.6	95	108	130.4	112

* Assumed twice the filtrate volume at 7.5 min.

Conclusion

- An optimum fly ash slurry formulation developed in this study meets the industry requirements even under the most severe cases
- All fly ash sources selected in this study show that the compressive strengths of fly ash plugs in excess of 500 psi after one week of curing time regardless of the curing temperature
- Fluid losses of each fly ash source are within a recommended value of fluid loss without adding any special filter loss control additives

Future Work

- A practical process to place fly ash slurry needs to be developed under bottomhole conditions
- The fly ash grout plugging quality also needs to be verified by using both laboratory and the actual well tests
- It is required to develop the technology to place a fly ash slurry through coiled tubing without employing conventional rig

Acknowledgement

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