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Effect of Perlite Particles on Barite Cement Properties

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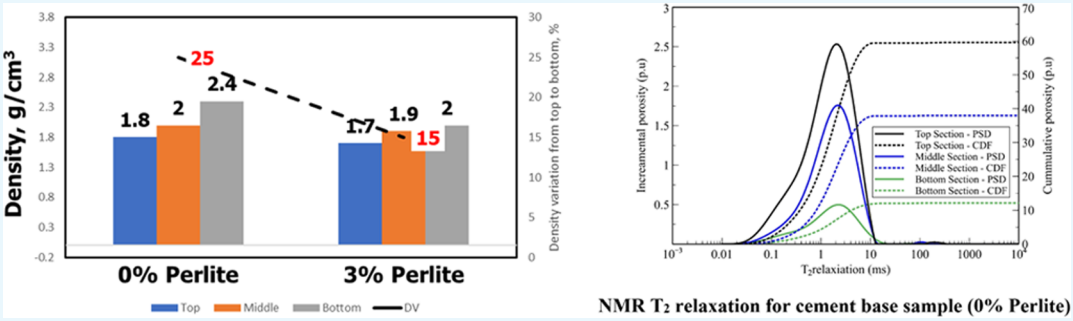

NMR T_2 relaxation for cement base sample (0% Perlite)

ABSTRACT: Conventional heavy-weight oil and gas well cement systems formulated with barite exhibit high viscosities. Additionally, the heavy-weight powder tends to settle, causing density variation and disruption in the porosity of the hardened cement cores. Studies have shown that such problems can be mitigated by controlling the particle size distribution of the cement system. The main objective of this study is to evaluate the effect of perlite powder particles on the fluid and hardened properties of barite-based cement systems. Barite heavy-weight cement slurries containing 0, 1, 2, and 3% by weight of dry cement (BWOC) of perlite powder were prepared. The rheological study was performed at a bottomhole circulating temperature (BHCT) of 150 °F and ambient pressure. An ultrasonic cement analyzer (UCA) and a high-temperature−high-pressure (HTHP) curing chamber were used to cure samples for 24 h at a bottomhole static temperature (BHST) of 292 °F and pressure of 3000 psi. Porosity measurements were performed using the nuclear magnetic resonance (NMR) technique. The results indicate that the incorporation of perlite powder into conventional barite-based heavy-weight cement slurry causes modifications in the properties of the systems. In general, the plastic viscosity decreases, while the yield point and gel strength increase with increasing perlite concentration. The reduction in plastic viscosity also reduces the pump pressure, while the increase in yield point and gel strength reduces particle sedimentation. Additionally, the compressive strength and tensile strength of hardened cement increase, while the wait-on-cement time decreases. NMR studies indicate that perlite reduces the porosity variation that exists in conventional barite-based cement systems due to the formation of stable cement systems.

1. INTRODUCTION

Oil-well cementing is a multipurpose operation, where cement slurries prepared by admixing water, cement, and various additives are pumped downhole to isolate producing intervals, protect the casing, carry out remedial operations, control circulation losses, or abandon the well.[1−4]

Various admixtures are used in the cement slurry to improve its plastic and solid properties.[5] Weighting materials are additives with a specific gravity greater than that of cement.[6] When the objective is to cement unstable and high-pressure intervals such as those encountered in deep oil and gas wells, weighting materials are used to increase the density of neat cement systems to 17.5 ppg and above.[7−10] Commonly used weighting materials include barite, manganese tetroxide, ilmenite, and hematite.[6,9−12]

Research in the area of heavy-weight cement has been focused on performance assessment of new weighting materials and optimization of conventional heavy-weight systems. Al-Yami et al.[13] proposed a new high-density cement formula composed of two weighting materials, iron oxide and manganese tetroxide, and other admixtures for use in gas-bearing wells. The performance of the slurry evaluated as per the standardized procedure improved when these weighting materials were combined than being used individually in formulations.

Saasen and Log[12] studied the influence of dust collected from the ilmenite processing plant on cement rheology. The composition of the material suggested that it would have high density and could be an alternative to barite; however, the

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findings suggested that the effect of the material on the flow behavior of cement is unsatisfactory. Johnston and Senese[14] proposed a water-dispersible additive, with a density comparable to that of hematite as a substitute weighting material. The material was obtained as a residue in the production of ferromanganese. Tests showed that the material does not settle out. As indicated by the workers, the reduction in sedimentation, cost-effectiveness, and ease of handling makes this material a better alternative to hematite.

An evaluation of the impact of different weighting additives on the properties of cement composite was performed by Ahmed et al.[9] Different heavy-weight cement systems were prepared at 18 ppg with iron oxide (hematite), ilmenite, and barite. The study indicated that the ilmenite-based cement system has less variation in density and, due to its small particle size distribution, produced excellent results. The barite-based cement, on the other hand, showed the most variation in density and lowest strength. Al-Bagoury et al.[8] reported that when the particle size of weighting materials is reduced, settling-out is eliminated and the properties of the cement system are enhanced. The authors studied the effect of micronized ilmenite with a median size of 5 μm on slurry behavior. It was observed that the small size of ilmenite prevented settling and allowed for enhancement in rheology and strength.

According to Caritey and Brady,[15] in very high temperature and pressure conditions, some heavy-weight additives (hematite, manganese, and titanium oxides) become reactive, adversely affecting the strength and permeability of the hardened cement matrix. However, this phenomenon was not observed with barite. Also, investigations have revealed that the existing heavy-weight cement systems have poor rheology.[8] Other challenges encountered in the use of conventional heavy-weight cement systems include high solid volume and high viscosity, making it difficult to blend and pump them.[10,14] Additionally, weighting materials disrupt cement homogeneity as a result of settling.[9] When settling occurs, the ability of the slurry to control gas migration reduces.[13]

The above discussions highlight the amount of research work that has been done in search of stable heavy-weight cement systems. The objective of the current study is to investigate the effects of perlite, an aluminosilicate material, on the stability, rheology, and strength of barite-based cement systems.

1.1. Applications of Perlite in Cement and Drilling Fluids. Perlite is a silica-based volcanic glass composed of high moisture content, about 2−5%.[16,17] When heated at temperatures in the range of 1650−1832 °F, the water vaporizes and the rock pops, forming white popcorn-like shapes.[17−19] Its new form, termed expanded perlite, is a lightweight material with the pozzolanic property.[17−21] The incorporation of perlite in cement-based composites improves workability and enhances thermal insulation.[22,23] Besides its use in formulating low-density cement systems,[24,25] perlite is also used as a bridging agent in both mud and cement systems.[26−28] According to a study on the effect of perlite powder on filtration properties of a barite-based mud system performed by Bageri et al.,[28] the inclusion of the material increased the yield point and hence the ability to effectively transport cuttings and reduced the mud cake thickness and volume of the filtrate.

According to Al-Bagoury et al.,[8] the particle size of cement admixtures is key in formulating a high-performance cement system. This study seeks to study the effect of perlite particles on the properties of a barite-based cement system. It is a recommended practice to undertake preliminary studies to assess the impact of any additive on the plastic and hardened properties of a cement system before field applications. The testing procedure and properties such as rheology, wait-on-cement (WOC) times, density variation, porosity, and strength would be investigated following API standards.[29,30]

2. RESULTS AND DISCUSSION

2.1. Effect of Perlite Powder on Rheological Behavior. The rheological parameters plastic viscosity, yield point, and gel strength of cement systems are presented in Figures 1−3,

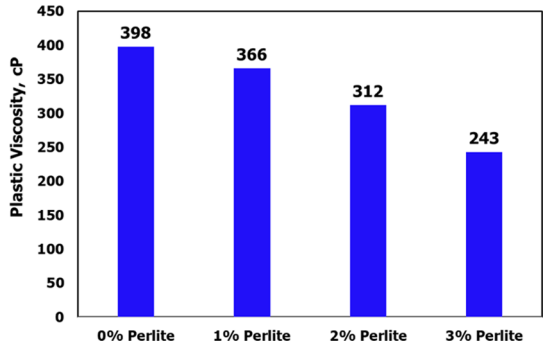

Figure 1. Plastic viscosity for barite-based cement.

respectively. The fluid viscosity is an essential property that controls the pump pressure.[31] As observed in Figure 1, the plastic viscosity of the barite-based system decreased with increasing perlite concentration. The addition of 3% perlite reduced the plastic viscosity by 39%. The addition of 1% perlite had a lower viscosity than the 0% perlite system.

The yield point is a very important flow parameter. It controls the attractive forces between particles and describes the lowest stress needed to cause fluid deformation.[32,33] A high yield point is ideal as it improves the carrying capacity of the slurry.[34] However, this results in an increase in the initial pump pressure as the yield point also indicates the force to overcome to start a flow.[35] The yield point of the barite-based heavy-weight cement slurries increased with increasing perlite content (Figure 2). The yield point increased by about 242%, 531%, and 958% for 1%, 2%, and 3% additions, respectively.

The gel strength, on the other hand, represents the ability of the cement system to develop attractive forces under static

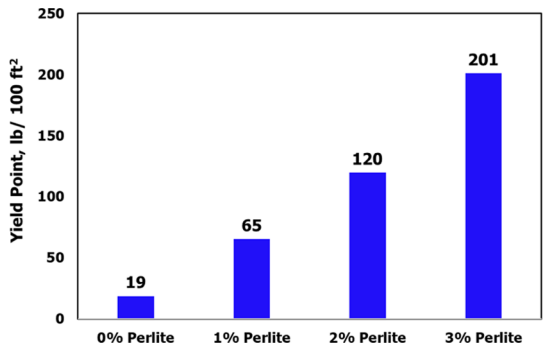

Figure 2. Yield point for barite-based cement.

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conditions, and it controls fluid migration up the annulus.[36] The plot (Figure 3) shows that the gel strength increased with

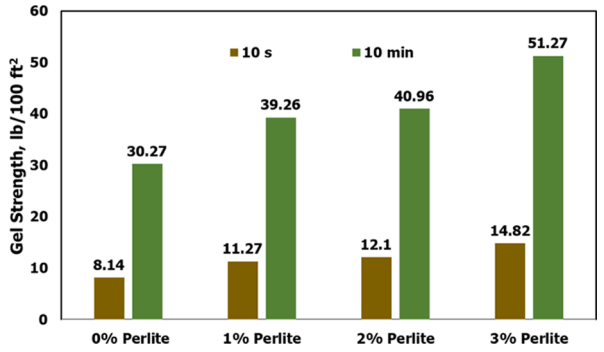

Figure 3. Gel strength for barite-based cement.

increasing perlite content. For instance, the cement composite consisting of 3% perlite had an increase of 82% in the 10 s and 69.38% in the 10 min gel strength.

These results show that the addition of perlite powder to barite cement systems results in the modification of rheological behavior. The plastic viscosity decreases, while the yield point and gel strength of the slurries increase with increasing perlite concentration.

2.2. Effect of Perlite Powder on Strength. The UCA helps monitor strength development with time, especially at an early age. The 24 h compressive strength of the slurries is shown in Figure 4. The experiment was conducted at a

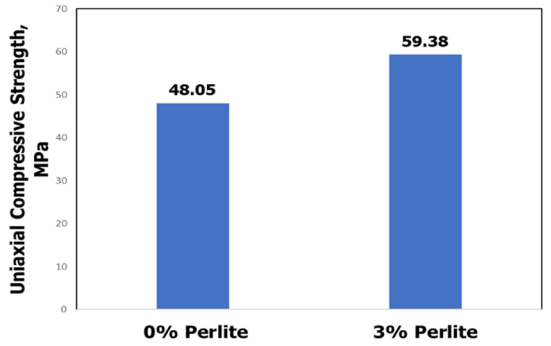

Figure 4. Uniaxial compressive strength.

bottomhole static pressure (BHST) of 292 °F and pressure of 3000 psi. The study showed that the addition of perlite powder improved the compressive strength of set cement. The 24 h sonic strength of the barite-based slurry increased from 48.05 MPa for 0% perlite powder to 59.38 MPa for 3% perlite powder, representing a 23.58% increase in strength.

Figure 5 compares the tensile strength of the 3% perlite systems to that of the control cement matrix. The incorporation of perlite particles enhanced tensile strength. The tensile strength of the base barite containing 0% perlite was 3.31 MPa and that for the 3% perlite system was 4.75 MPa. The increase in mechanical properties can be attributed to the extra cementitious materials produced through the pozzolanic activity of perlite.[21]

The time to achieve a compressive strength of 500 psi for the slurries is presented in Table 1. This is the wait-on-cement time, which indicates the time allowed for the cement to set and develop sufficient strength to support the casing before

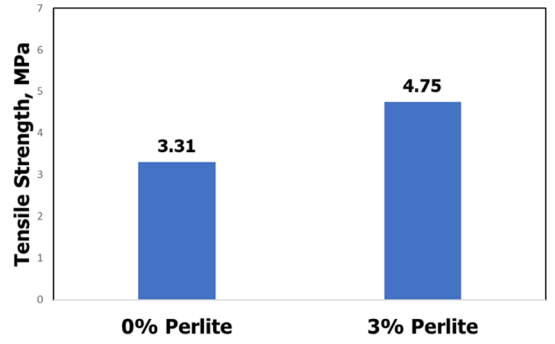

Figure 5. Tensile strength.

Table 1. Wait-on-Cement Time (h/min) to Reach 500 psi

sample	0% perlite	3% perlite
barite-based slurry	5:22	4:58

drilling out the casing shoe.[37] This time could vary from hours to days depending on various conditions such as field practice and depth of cement placement.[38,39] The addition of 3% perlite powder to the barite slurry resulted in a general reduction in WOC time.

2.3. Effect of Perlite Powder on Density Variation. Figure 6 shows the contrast in density along with the vertical

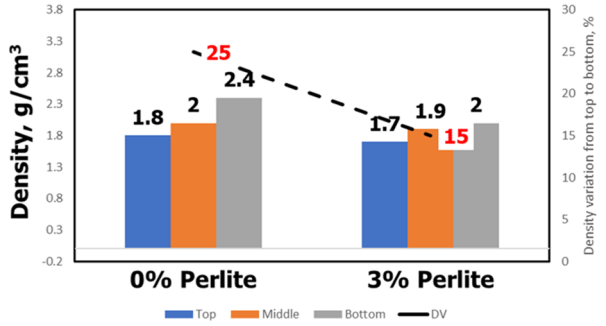

Figure 6. Densities of the top, middle, and bottom sections of cylindrical cement samples.

orientation of cylindrical cement samples formed with the slurries under study. These cores were demolded after curing for 24 h under temperature and pressure conditions of 292 °F and 3000 psi, respectively. Each core is represented by three different sections: top, middle, and bottom. The density of each section was computed after drying the sections to a constant weight. The graph also shows the percentage of density contrast between the top and bottom of each cement core. The degree of density variation correlates with the heterogeneity of the cement system. The lower the density variation (DV) between the top and bottom of the cylindrical cement cores, the more homogeneous the system.

The results indicate that the conventional barite system has a high settling tendency (25%). This is because of high specific gravity (4.48 g/cm^3), which promotes particle sedimentation. However, the percentage variation between the top and bottom samples with 3% perlite powder decreased to 15%. It was obvious that the harsh conditions of high pressure and high temperature could weaken the performance of viscosity additives, which led to a severe reduction in the suspension capacity. Meanwhile, the capability of the perlite particles to

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adapt and expand in such conditions,[28] in addition to their strong dispersion in these conditions, inevitably sustained the viscosity features (yield point) of the cement, thereby raising the sag stability of the cement.

2.4. Effect of Perlite Powder on Porosity. The NMR technique was used to evaluate the impact of the perlite particles on porosity. The test was performed on 4 inch length cylindrical cement cores. The cement cylinder was cut into three sections (top, middle, and bottom) to assess the deviation in the porosity through the cement column. The NMR measurement of the middle section was used as a reference sample for the other two sections.

The NMR pore size distribution function (PDF) and cumulative distribution function (CDF) results of the 4 inch length cement samples, 0% perlite (here tagged 0% PPA) and 3% perlite systems, are shown in Figure 7. Continuous lines

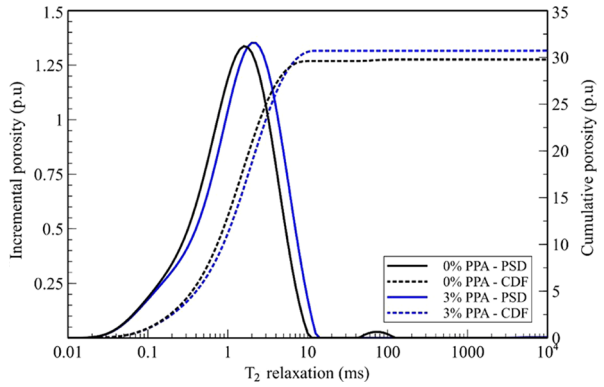

Figure 7. NMR T_2 relaxation for 4 inch length cylindrical samples.

represent the PDF, while broken lines represent the CDF. The porosity distribution after adding the perlite particles showed only a slight increment in porosity, with a porosity of 29.7% for the 0% perlite and 30.7% for the 3% perlite systems.

The difference between the PDF and CDF curves for the three sections of the base cement sample (0% PPA) is conspicuous, as shown in Figure 8, which presented the difficulty of formulating the high-density cement with a stable sagging index. This observation confirmed a large density variation between these three sections of the base sample. However, the incorporation of perlite reduced particle sedimentation to a greater extent, Figure 9.

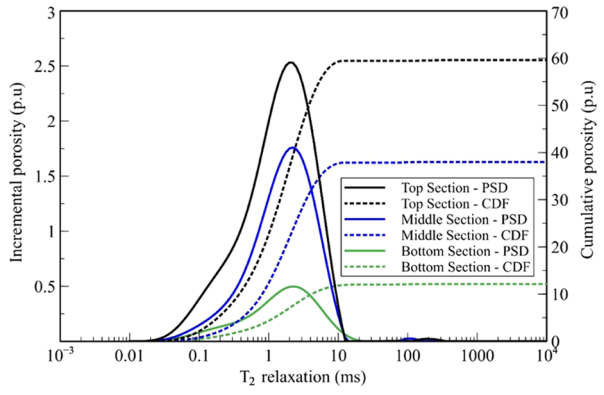

Figure 8. NMR T_2 relaxation for the cement base sample (0% perlite) at three different sections (top, middle, and bottom).

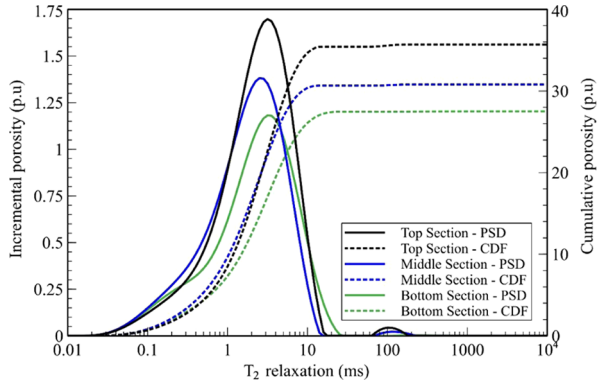

Figure 9. NMR T_2 relaxation for the cement base sample (3% perlite) at three different sections (top, middle, and bottom).

Figure 6 shows that the heavy material accumulated in the lower section and hence had a higher density compared to the middle and top sections. As a result, the porosity of the bottom section was lower than that of the other two sections. For the control sample containing 0% perlite, the increase in the porosity of the upper section with respect to the middle section was 21.5%, while the reduction in the bottom section porosity with respect to the middle section was 25.8%, as shown in Table 2. This extreme difference between the three sections' porosity was controlled by adding a 3% concentration of perlite particles. The difference in the upper and middle section porosities reduced significantly down to 4.9% as shown in Table 2. Also, the percentage reduction in porosity for the bottom section in comparison to the middle section was even much lower (3.31%). These observations could be attributed to the fact that adding a 3% concentration of perlite particles promoted suspension and carrying capacity of cement as proven earlier.

Table 2. Porosity Measurement Using NMR for the Top, Middle, and Bottom Sections of the Cement Cylinder

	porosity %		difference in porosity with respect to middle section	
perlite concentration (%)	0	3	0	3
top section	59.56	35.69	21.57	4.89
middle section	37.99	30.80		
bottom section	12.11	27.49	25.88	3.31

3. CONCLUSIONS

The effect of perlite powder on heavy-weight barite cement was studied. The following conclusions are drawn.

1 The plastic viscosity of barite heavy-weight cement decreased with increasing perlite powder concentration, while the yield point and the gel strength increased.
2 The addition of perlite powder improved the compressive strength of set cement. The 24 h sonic strength of the barite-based slurry increased from 48.05 MPa for 0% perlite powder to 59.38 MPa for 3% perlite powder, representing a 23.58% increase in strength.
3 The wait-on-cement time decreased with the addition of perlite powder.

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Table 3. Elemental Composition of Raw Materials (wt %)

samples	Na	Al	Cl	Ca	Ti	Si	S	K	Fe	Ba
barite		1.96				5.18	15.84	1.34	0.97	69.36
cement		2.16		74.06	0.31	12.52			9.71	
perlite		10.31		1.74	0.53	58.73			1.95	
silica flour		0.61		0.27	0.14	98.84			0.06	

4 Perlite particles reduced the settling tendencies of barite powder due to its improvement in viscosity, yield point, and gel strength.

4. MATERIALS AND METHOD

Heavy-weight cement slurry was prepared with Class G cement, silica flour, barite, and perlite. Table 3 shows the elemental composition of these materials. The key elements in barite are barium, sulfur, and silicon. A small amount of potassium, aluminum, and iron is also present in the barite particles. Class G cement contains about 74 wt % calcium and a substantial amount of silicon and iron. Silicon and aluminum are the major elements in perlite, while silica flour is predominantly silicon.

The plots of particle size distributions (PSDs) of the raw materials are shown in Figure 10. The median size values, D_{50},

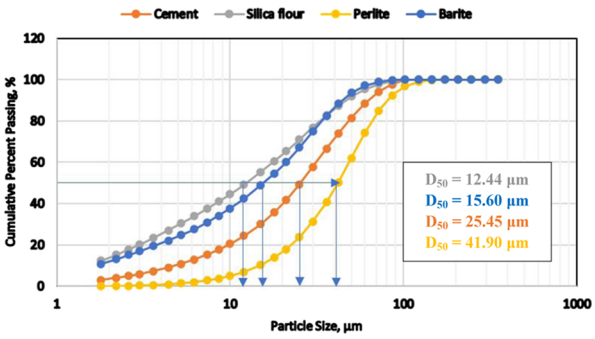

Figure 10. Particle size distribution of raw materials.

Table 4. Summary of PSD

description, μm	silica flour	barite	cement	perlite
D_{50}	12.44	15.60	25.45	41.9

used to characterize the powders are given in Table 4. The figure and table show that silica flour has the smallest size distribution with a median value of 12.44 μm, while perlite has coarse grains with a median size of 41.9 μm. The D_{50} values for barite and Class G cement are 15.6 and 25.45 μm, respectively.

In this study, barite-based heavy-weight cement systems were prepared with 0, 1, 2, and 3% of perlite powder. The cement, silica flour, and weighting material were dry-mixed and added to the water phase containing a fluid loss additive, retarder, and defoamer. The mix was admixed within 15 s while stirring at 4000 rpm and additionally 35 s at 12 000 rpm.

Table 5 presents the various proportions of admixtures used in formulating the heavy-weight systems. An atmospheric consistometer was used to condition the slurries at a bottomhole circulating temperature (BHCT) of 150 °F for 20 min. Afterward, the rheological behavior of the slurries was

Table 5. Mix Proportions

component	names	BWOC (%)	weight (gm)
cement	class G	100	600
silica flour	SSA-1	35	210
weighting material	barite	32.87	197.22
fluid loss	Halad-413	0.5	3
dispersant	CFR-3	0.25	1.5
retarder	H-12	1.5	9
water	distilled water	44	264
defoamer	D-Air 3000L	4.70×10^7	2.82×10^6
new material	perlite	0	0
		1	6
		2	12
		3	18

determined at 150 °F and ambient pressure conditions using a Grace M3M600 viscometer and M3600DAQ software.

An ultrasonic cement analyzer (UCA) and a high-temperature−high-pressure (HTHP) curing chamber were used to cure samples for 24 h at a bottomhole static temperature (BHST) of 292 °F and pressure of 3000 psi for compressive strength analysis. The tensile strength, porosity, and settling of the weighting materials were measured using the hardened cylindrical cement cores.

The porosity and pore size distribution of the cylindrical cement plugs were measured using a low-magnetic-field (2 MHz) NMR relaxometry system "Geospec rock analyzer" from Oxford instruments, United Kingdom. In NMR relaxometry, the surface relaxation time, T_2 (ms), of the fluids saturating a porous medium was correlated with the pore size. The NMR signal coming from the saturated medium decreased exponentially with time.

A Laplace inversion of the exponential decay function will give the probability density function (PDF) of the T_2 values in the porous medium. Each T_2 value has a one-to-one correspondence with the pore sizes in the medium such that the PDF of T_2 represents the pore size distribution of the porous medium. The cumulative density function (CDF) plot is a summation of the different pores' volume (or porosity) and peaking at a value representing the total porosity or pore volume of the rock.[40] The pore size distribution function (PDF) and cumulative distribution function (CDF) of the cement sample were measured at three different sections (at the top, middle, and bottom) to compare the porosity homogeneity through the same sample.

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Author Contributions

All authors contributed to all aspects of this manuscript and have read and agreed to the published version of the manuscript.

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