Quality Assurance and Quality Control of Well Cement Designs Using Resistivity and Resistivity Index

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Abstract: In this study, smart cement mixing and testing samples quality control and assurance is verified using resistivity as an indicator. Several tests were conducted to prove that resistivity is sensitive to cement parameters. Resistivity measurement is a reliable method to not only ensure the quality of the cement mix but also to quantify the changes associated with cement hydration and phase change.

1. Introduction:

Well cement slurry design in the laboratory is a trial and error based method that is subject to many hereditary errors. These designs are managed by engineers with years of experience in cement design and operations, yet, the tests performed in the laboratory are idealized and may not reflect actual field conditions. Currently with API standards for well cement slurry quality control measure, the only parameter required and that is currently used in the industry is density of slurry taken immediately after mixing. Although, density is a material property just like resistivity, there are two shortcomings of relying on density only to characterize cement slurry. First disadvantage would be the fact that density measurements are often conducted using a mud balance which is bounded to have many errors associated with testing procedures. The second shortcoming of relying on density as a quality control measure would be due to the fact that there are currently no methods available to measure the density while performing the tests on cement samples in order to detect changes and monitor cement quality real-time. For these reasons, resistivity was introduced to measure the quality of cement mix as resistivity could be measured in the sample being blended immediately after mixing eliminating by that the human factor errors associated with density measurement. Also since resistivity is a material property that is sample independent it will be used to quantify the amount of water and additives in order to optimize cement slurry designs. This could be a valuable parameter to the API procedures as currently API only considers one or a few points of time during the setting process (Vipulanandan 2015).

2. Objective:

The specific objectives of this study are the following:

a) Verify the sensitivity of resistivity parameter to the quality of mixing.
b) Prove that resistivity is sensitive to different cement parameters.
c) Compare different methods for cement testing with testing procedures modified with resistivity.
d) Introduce resistivity index for QA/QC in well cement laboratory testing.

3. Materials and Method:

Class H cement 0.38 water to cement ration (w/c) using (350 g) cement and (132 mL) of water and conductive fillers 0.1%. Latex polymer additive added as (1%, 2%, 3%, 5% BWOC) (Carboxylated styrene butadiene latex XSBR). The tests were done under atmospheric pressure and varying temperatures. The machine was calibrated with 100 cp viscosity calibration fluid. Testing was done in accordance with API RP10B-2 testing standards and procedures by mixing the polymer with water first then cement with carbon fibers dispersed inside was poured into the blender while spinning at 4000 RPMs within 15 s. Then the slurry was mixed for 35 s at 12000 RPMs. Initial density (using standard mud balance) and initial resistivity were both measured immediately after cement mixing. Final Resistivity was recorded after the test was done.

4. Discussion

Table 1. Cement Parameter Changes Detected by Resistivity

Parameter	Resistivity Sensitivity	Impact on Resisitivity
Moisture	• Fluid loss • Water-to-cement ration W/C • Free Fluid	Increases with moisture loss
Temperature	Temperature variation	• Slurry phase: Increases • Set phase: Decreases
Pressure	Applied pressure variations	• Slurry phase: Increases • Set cement: Decreases
Compressive Stress	Applied stress (piezoresistivy)	Set cement: increases

Table 2. Cement Laboratory Testing and Resistivity Index

Test	Parameter	Resistivity	Resistivity Index
Fluid Loss	Fluid Volume	increases	Positve
Compressive Strength	• 500 psi • Ultimate compressive strength	increases	Positive (piezoresistive strain)
Gas Migration	Gas Velocity	increases	• Slurry phase: positive • Set phase: negative
Rheology	• Plastic viscosity • yield point	decreases	Negative
Static Gel Strength	(50, 100, 500) lbf/100 ft^2	increases	Positive

5. Testing and Results:

Table 3. Smart Cement Density and Change in Resistivity with Polymer Loading

BWOC	DENSITY			INITIAL RESISTIVITY	FINAL RESISTIVITY	RESISTIVITY INDEX
%	lb/gal	g/cm^3	lb/ft^3	Ω.m	Ω.m	%
0	16.4	1.96	123	1	0.959	- 4.10
1	15.8	1.89	118	1.01	0.965	- 4.46
2	15	1.79	112	1.04	0.974	- 6.35
3	14.1	1.69	105	1.1	0.983	- 10.64
5	12.4	1.49	93	1.23	1.04	- 15.45

Table 4. Change in Smart Cement Resistivity with Polymer Loading and Temperature Variations

BWOC %	*1 %*			*3 %*		
Temp.	Initial Resistivity	Final Resistivity	Resistivity Index	Initial Resistivity	Final Resistivity	Resistivity Index
ºF	Ω.m	Ω.m	%	Ω.m	Ω.m	%
20	1.011	0.965	- 4.537	1.100	0.983	- 10.64
40	1.149	1.082	- 5.844	1.235	1.157	- 6.25
60	1.397	1.282	- 8.205	1.538	1.429	- 7.14

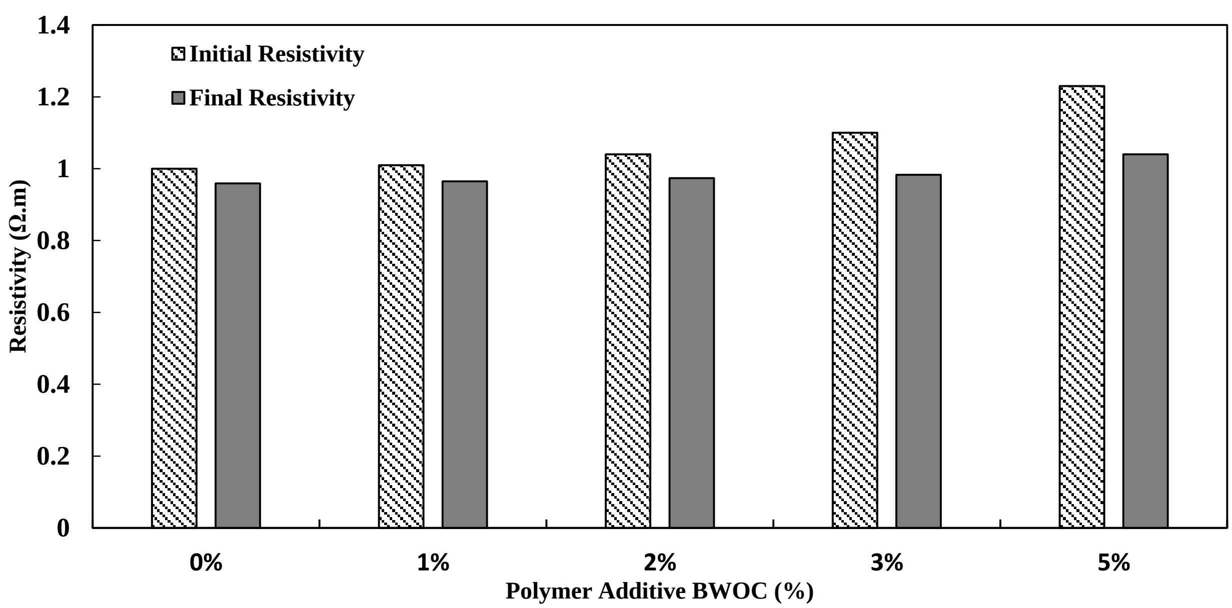
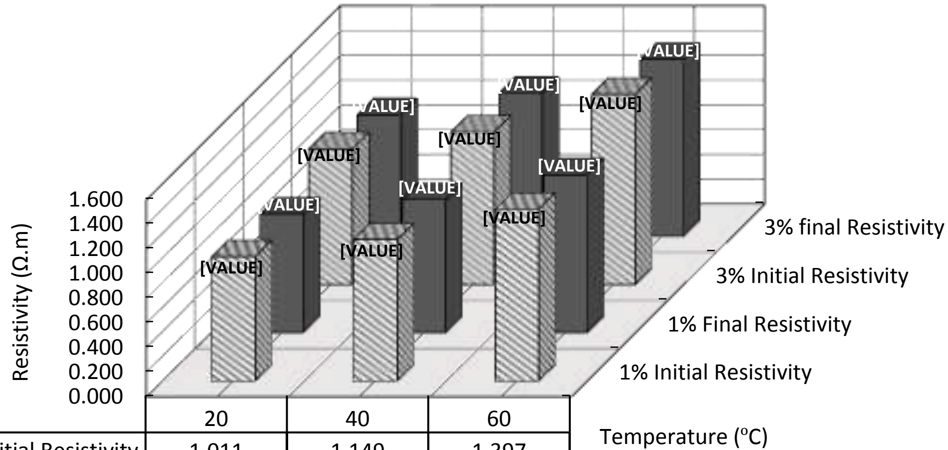


Figure 1. Change in Smart Cement Resistivity with Polymer Loading



	20	40	60
1% Initial Resistivity	1.011	1.149	1.397
1% Final Resistivity	0.965	1.082	1.282
3% Initial Resistivity	1.100	1.235	1.538
3% final Resistivity	0.983	1.157	1.429

Figure 2. Change in Smart Cement Resistivity with Polymer Loading and Temperature

6. Conclusion:

1. Resistivity can be used as a quality control measure to assure the quality of cement throughout the testing period as resistivity is sensitive to cement phase change and time dependent chemical reactions.
2. Early gel strength development can be detected using resistivity. This is very crucial for zonal isolation and gas migration prevention.
3. Resistivity index quantifies the rate of hydration reaction, moisture loss as well as magnifies cement strain (piezoresistive strain).
4. Resistivity can recorded throughout the tests performed continuously as opposed to density which is usually measured initially after mixing.
5. Both resistivity and resistivity index can be used as quality control and quality assurance measures for both cement lab testing and field operations.

7. Acknowledgements:

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8. References:

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