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Research Article

Designing of Cement Slurry to Enhance Compressive Strength and Rheology: An Experimental Study

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Abstract

The most essential function of oil and gas well cement is to provide isolation of zones in a production well. Cement isolates the wellbore in completion of oil and gas wells, prevents failure of casing, and it also prevents wellbore fluids so that they cannot be contaminated from fresh water aquifers. In slurry state cement is distinguished by rheological properties like plastic viscosity and yield stress. Proper selection of cement slurries plays a vital role in well commenting and that could be possible with the utilization of efficient materials that may results the superior rheological properties of cement slurry i.e. plastic viscosity, gel and yield strength. The selection of cement has been done on account of higher values of compressive strengths for which quality of cement sheath will be enhanced. Cement Slurry design can be optimized by operators for which it is mandatory for operators that they have knowledge about actual temperature that cement will encounter inside wellbore. Down hole temperatures of cementing have impact on thickening time, rheology, and compressive strength development. In this research work Rice Husk Ash (RHA) and Egg Shell Powder (ESP) are used in cement slurry so that compressive strength of cement specimen can be increased. The cement slurry has been made from locally manufactured cement, water, RHA and ESP. Cement slurry of 600ml by volume has been prepared. Specimens with size of 2×2×2 inch cubic molds are made for compressive strength testing at different curing conditions. Three variants of the specimen with varying concentrations of RHA and ESP are made. In present work during slurry state the rheological properties are determined while in solid state compressive strength of cement specimen at three curing ages of 08 hours, 24 hours and 72 hours is determined.

Keywords: *Compressive strength, Rheological properties, well bore fluids, plastic viscosity, thickening time, cubic mold and curing ages.*

1. Introduction

Oil well cementing has been played a vital part in producing the hydrocarbons from subsurface to surface successfully. In oil and gas well completion, cement isolates the wellbore, prevents casing failure and to form a competent hydraulic seal during the whole operational lifetime of the well for long-term zonal isolation (Parcevaux, P. A., and P. H. Sault, 1984). The stresses inside the wellbore get increased and resultant cement sheath integrity damaged because of rock movement (Erik B. Nelson and Dominique Guillot, 2006).

The down hole environment (temperature, pressure, formation water chemistry) will govern the design of the cement slurry and impact on the performance across the full lifecycle of a well. The density and rheological properties will determine the success of the initial placement of the cement (Anna Pikłowska, 2017).

During the operational life, variations in temperature and pressure will occur. Knowledge of the behavior of the set cement material due to the curing temperature and pressure and there after changes in the material response (stiffness, ductility etc) owing to changes in temperature and applied stresses, including fatigue degradation due to loading cycles, is vital in ensuring the reliability of well designs (Heinold, *et al*, 2002).

Additives like RHA and ESP are mixed in cement slurry in order to increase compressive strength of cement sheath during cementing of oil well where there are high pressures and high temperatures concerned. Cement selection is based on the high values of compressive strength and as an outcome cement of improved quality will be obtained.

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1.1 Compressive Strength

The compressive strength is played vital importance and has tested the accuracy of oil well cementing and has capability to resist distortion when load has been applied. In general, the compressive strength increases with increase in curing time. The hydration is reaction between cement particles. The hydration has been accelerated with available of evaporated water (Falode OA, *et al*, 2013).

All tests related to compressive strength can be preceded before cementing job by Service Company. Cement compressive strength relies on additives used, mix designs, time of curing and exposure conditions. When cement gets set, it possesses compressive strength with passage of time. The compressive strength has produced in cement may be dependent on time, temperature, and pressure.

2. Research Methodology

This research project has been carried out to detect cement with maximum compressive strength and optimum rheological properties. In order to examine it, we have prepared cement samples with locally manufactured cement with addition of ESP and RHA with various concentrations.

2.1 Selection of Additives

In this project two additives are selected which enhance both rheological and mechanical properties of cement.

2.11 Eggshell powder (ESP)

Egg shells are obtained from nearby hotels and hostels of Jamshoro. Egg shell powder is obtained from egg shells. Due to present of $CaCO_3$ in ESP, it increases compressive strength of cement.

U.N Okonkwo, *et al* (2012) it's scientifically believed that eggshell is principally made of compounds of calcium carbonate (CaCO3) which is 93.7% of overall composition of the eggshell. Similarly, in production of cement calcium carbonate (CaCO3) is primary material.

2.12 Rice Husk Ash (RHA)

Rice husks are also obtained from rice mills nearby Jamshoro. Rice husk ash is formed from rice husk in incineration furnace. About 80-85% of silica is contained in RHA. RHA increases compressive strength of cement when specific amount of RHA is added into the slurry.

2.2 Materials and Specimen

Cement slurry was prepared from locally manufactured cement, water, RHA and ESP. Cement slurry of 600 ml by volume is prepared. The water is added to cement within limits of 50% to 66% bwoc. Specimens with size of 2×2×2 inch cubic molds are made for compressive strength testing. Three variants of the specimen are made in this study.

2.3 Experimental Work

The experiments are performed in laboratory on locally manufactured cement slurry to examine potential of locally manufactured cement mixed with oil well cement additives at test conditions of 90°C temperature and 20 MPa pressure. The cement slurry and preparation of specimen are carried out by closely following American Petroleum Institute (API) Specification 10A.

The specific quantity of every material has been weighted with electronic balance. The chosen amount of RHA has been added to water in cement blender at 1600 rpm, after 20 seconds, ESP mixed in cement slurry and it has been blended again for 20 seconds.

2.3.1 Plastic Viscosity and Gel strength

In slurry state rheological properties are determined. The fundamental reason to determine rheological properties is to forecast flow characteristics of cement slurry using Plastic Viscosity and Gel Strength. Slurry is preconditioned in consistometer before placing it in viscometer. Once preconditioning is completed, preheated cup of viscometer is filled by slurry and the test begins at desired temperature. Dial readings at six speeds i-e 600 rpm, 300 rpm, 200 rpm, 100 rpm, 6 rpm and 3 rpm are noted to calculate plastic viscosity. It is calculated by subtracting the reading at 600 rpm from the reading at 300 rpm. Gel strength is calculated at 10 seconds and 10 minutes.

2.3.2 Thickening Time Test

The HPHT Consistometer is used to determine the thickening time of the cement slurries at well bore temperature 90°C temperature and 20 MPa pressure. When BC value reaches 30 means the slurry loses its pump-ability. When its BC values reaches 70 or 100 means slurry has got thick.

2.3.3 Measurement of Slurry Density

After cement slurry has been prepared, there is dire need to verify its density either it is up to our need or target or not. While measuring the slurry density, we use the mud balance at a laboratory.

2.3.4 Compressive Strength Test

In hardened state compressive strength of cement is determined. The wet mix is then poured into 2×2×2 inch cubic molds and kept for 24 hours. Afterwards they are demoulded and kept for water curing for 08, 24 and 72 hours. Once samples have achieved specified curing at curing conditions of 90°C temperature and 20 MPa, pressure physical properties are examined by following API Specification 10A and API Recommended Practice 10B. The cubic molds of cement are tested in universal testing machine for compressive strength test.

3. Results and Discussions

3.1 Thickening Time

Results are determined by making 15 variants of cement slurry and in each variant five samples of cement slurry are tested in order to get average value of each test. ESP and RHA have accelerating effect therefore thickening times are getting decreased by increasing concentration of both additives. Results of thickening time tests are given in the Table No: 1

Table 1 Determination of thickening time with following ESP and RHA concentration.

Cement Slurry (ml)	ESP %	RHA %	Test condition	Thickening time (min)		
			$^{0}C \times Mpa \times min$	30 B_c	70 B_c	100 B_c
600	0	0	90x20x85	278	285	288
600	02	4	90x20x85	267	274	278
600	04	8	90x20x85	253	251	253
600	06	12	90x20x85	231	238	252
600	08	16	90x20x85	136	144	146
600	2.5	2.5	90x20x85	278	285	288
600	5	5	90x20x85	267	274	278
600	7.5	7.5	90x20x85	251	255	257
600	10	10	90x20x85	236	243	246
600	12.5	12.5	90x20x85	146	152	156
600	3	5	90x20x85	278	285	288
600	6	10	90x20x85	262	268	272
600	9	15	90x20x85	248	253	256
600	12	20	90x20x85	230	237	244
600	15	25	90x20x85	132	146	153

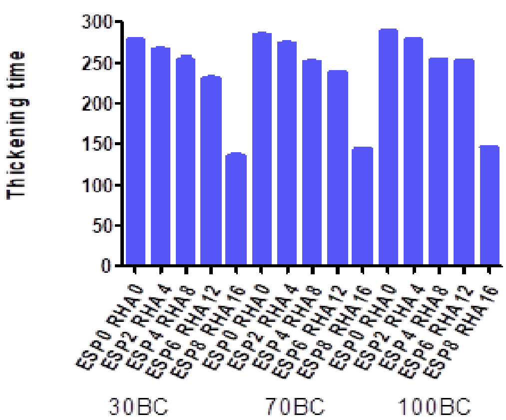

Fig: 1 Graph shows thickening time at 0 to 8% ESP & 0 to 16% RHA

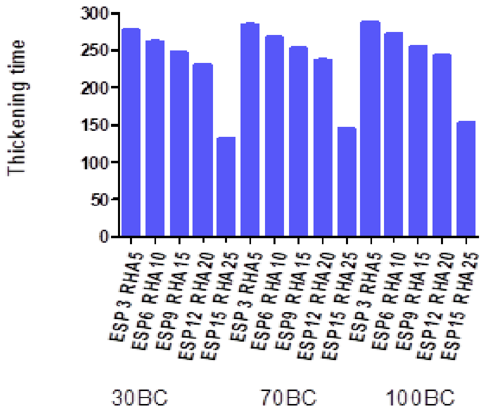

Fig: 2 Graph shows thickening time with 2.5% to 12.5% ESP & 2.5 to 12.5 %RHA

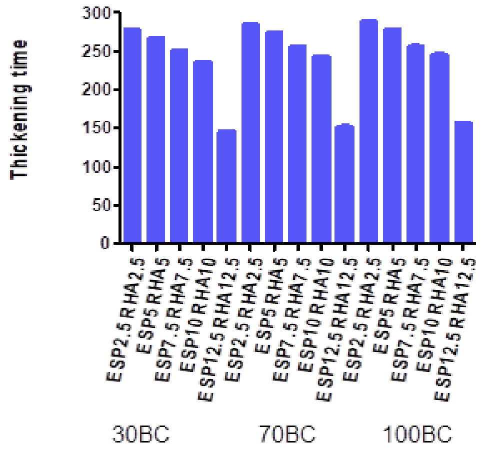

Fig: 3 Graph shows slurry thickening time with 3 to 15% ESP & 5 to 25 % RHA

3.2 Slurry density and Plastic Viscosity

Slurry density is determined by using mud balance. Plastic viscosity is determined using Rotational viscometer by taking dial readings at 6 speeds i-e 600 , 300, 200, 100, 6 and 3 rpm. Plastic obtained by: 600 rpm reading- 300 rpm reading. At concentration of ESP 15% and RHA 25% density obtained is 17.52 ppg which is higher than rest of all concentrations used shown in fig 08. But it is lowest 14.66 ppg with ESP 0% & RHA 0% shown in fig: 04. Slurry density is decreased with increasing the concentration of both additives. Values of densities of all cement slurries obtained between 14-17 ppg that are according to API specification and recommended practice 10B. Plastic viscosity is maximum i-e 67.2 cP with ESP 7.5% & RHA 7.5%. Whereas it is minimum with sample having ESP 10% and RHA 10% shown in fig: 07. The values of plastic viscosity of all cement samples are below 100 cP that is according to (Abbas *et al,* 2014) is favorable to retain cement slurry being pumpable. Test results of both Density and plastic viscosity are given in the Table no: 02.

Table 2 Determination of slurry density & Plastic Viscosity with following ESP & RHA concentration.

Cement Slurry (ml)	ESP %	RHA %	Test condition °C×Mpa	Slurry density (ppg)	Plastic viscosity (cP)
600	0	0	90x20	14.66	39
600	02	4	90x20	15.06	38.8
600	04	8	90x20	15.52	44.4
600	06	12	90x20	15.92	66.8
600	08	16	90x20	16.44	32.6
600	2.5	2.5	90x20	14.92	39
600	5	5	90x20	15.38	43.8
600	7.5	7.5	90x20	15.76	67.2
600	10	10	90x20	16.26	29
600	12.5	12.5	90x20	16.46	33
600	3	5	90x20	15.18	39.8
600	6	10	90x20	15.64	45.2
600	9	15	90x20	16.24	65.8
600	12	20	90x20	16.94	29.2
600	15	25	90x20	17.52	30.4

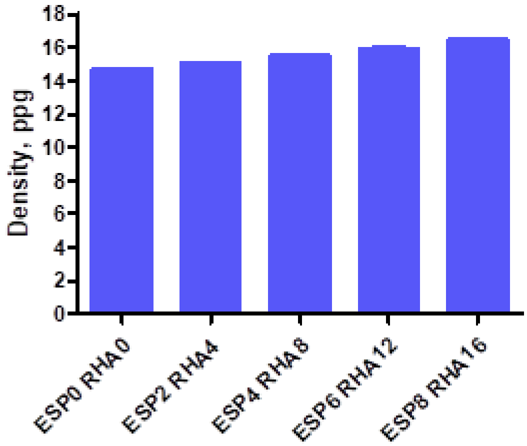

Fig: 4 Graph shows slurry density at 0 to 8% ESP & 0 to 16 %RHA

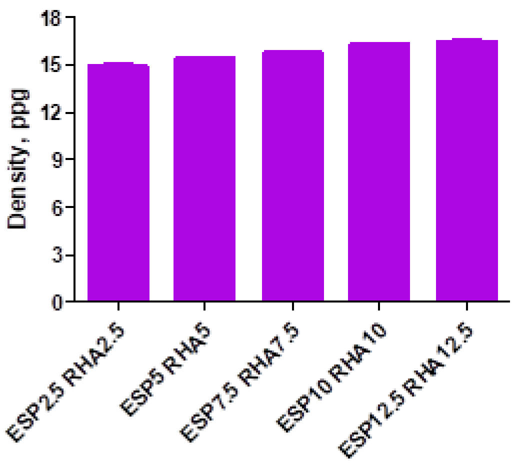

Fig: 5 Graph shows plastic viscosity at 0 to 8% ESP & 0 to 16 % RHA

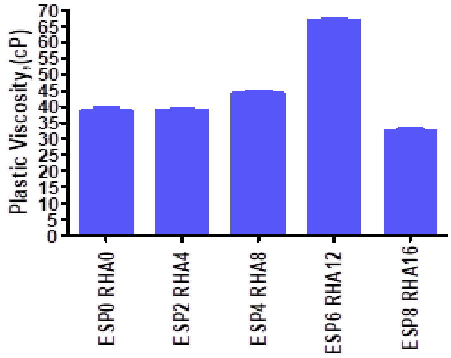

Fig: 6 Graph shows density at 2.5 to 12.5% ESP & 2.5 to 12.5 %RHA

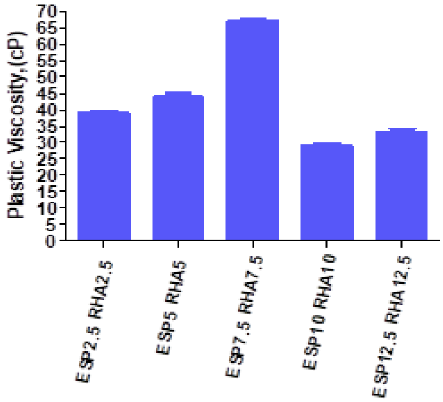

Fig: 7 Graph shows plastic viscosity at 2.5 to 12.5% ESP & 2.5 to 12.5 %RHA

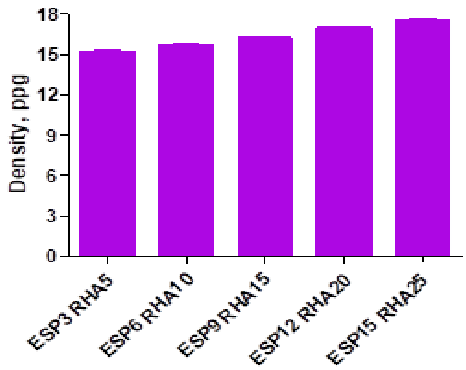

Fig: 8 Graph shows density at 3 to 15% ESP & 5 to 25 % RHA

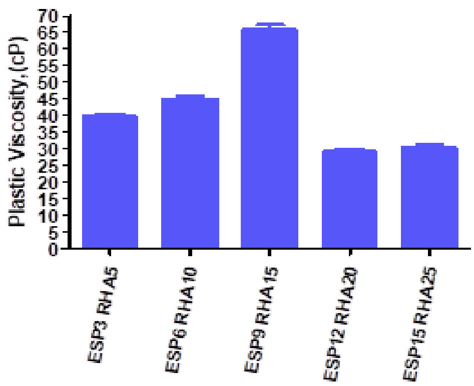

Fig: 9 Graph shows plastic viscosity at 3 to 15% ESP & 5 to 25% RHA

3.3 Gel Strength

Minimum Gel strength 6.2 and 18 lb/100 ft² with slurry having ESP0% & RHA0% at 10 seconds and 10 minutes respectively shown in fig: 10. Maximum gel strength 15.4 lb/ 100 ft² and 38.7 lb/ 100 ft² obtained with slurry having ESP 10% & RHA 10 at 10 seconds and 10 minutes respectively as shown in fig 11. In Table No: 03 concentrations of RHA and ESP and results obtained on these concentrations are given.

Table 03 Determination of Gel strength with following ESP & RHA concentration

Cement Slurry (ml)	ESP %	RHA %	Test condition ºC×Mpa	Gel Strength lb/100 ft²	
				10 Sec	10 min
600	0	0	90x20	6.2	18
600	02	4	90x20	6.3	18.1
600	04	8	90x20	9.0	22.3
600	06	12	90x20	11.1	29.4
600	08	16	90x20	13.1	33.3
600	2.5	2.5	90x20	6.4	18.2
600	5	5	90x20	9	22.3
600	7.5	7.5	90x20	11.1	29.4
600	10	10	90x20	15.4	38.7
600	12.5	12.5	90x20	13.1	33.4
600	3	5	90x20	7	18.3
600	6	10	90x20	9.1	22.3
600	9	15	90x20	11.1	30
600	12	20	90x20	15.3	38.5
600	15	25	90x20	13.7	33.5

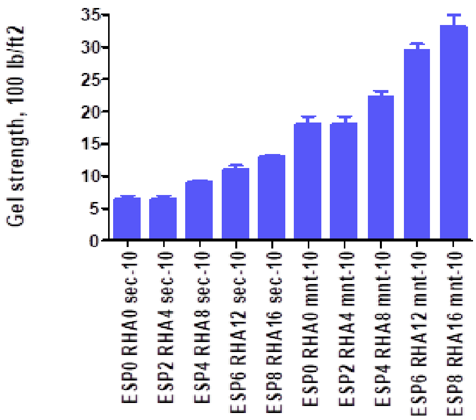

Fig: 10 Graph shows gel strength at 0 to 8% ESP & 0 to 16 % RHA

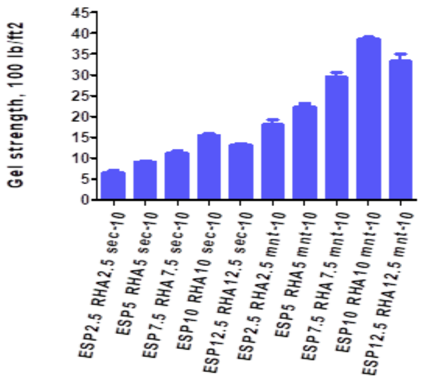

Fig: 11 Graph shows gel strength at 2.5 to 12.5% ESP & 2.5 to 12.5 %RHA

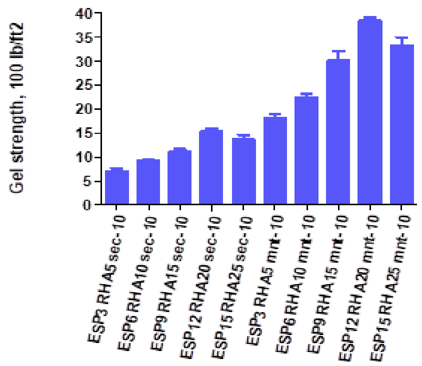

Fig: 12 Graph shows gel strength with 3 to 15% ESP & 5 to 25 %RHA

3.4 Compressive Strength

The sample with ESP 10% and RHA10% showed high value of CS 30.16 MPa at curing period of 72 hours. At curing period of 24 hours with same ESP & RHA% the value of CS obtained is 20.44 MPa. While at the curing period of 08 hours, the value of CS is 14.10 MPa which is lower than curing periods of 24 hours and 72 hours shown in fig: 14.

The sample with ESP 0% and RHA0% showed lowest value of CS 23.02 Mpa, 13.18 Mpa and 4.16 MPa at curing period of 72 hours, 24 hours and 08 hours respectively shown in fig: 13.

Table 04 Determination of Compressive strength with following ESP & RHA concentration**.**

Cement Slurry (ml)	ESP %	RHA %	Test condition □×Mpa	Compressive Strength (MPa)		
				8 hrs	24 hrs	72 hrs
600	0	0	90x20	4.16	13.18	23.02
600	02	4	90x20	7.14	16.52	25.56
600	04	8	90x20	9.56	17.50	27.26
600	06	12	90x20	12.18	21.50	29.46
600	08	16	90x20	13.58	19.34	30.16
600	2.5	2.5	90x20	6.86	15.04	24.20
600	5	5	90x20	9.08	17.52	25.60
600	7.5	7.5	90x20	11.14	18.72	26.30
600	10	10	90x20	14.10	20.44	31.32
600	12.5	12.5	90x20	12.12	19.80	29.54
600	3	5	90x20	8.46	16.26	26.16
600	6	10	90x20	9.12	16.82	26.74
600	9	15	90x20	13.06	19.60	29.84
600	12	20	90x20	11.28	17.84	28.12
600	15	25	90x20	9.20	15.80	25.28

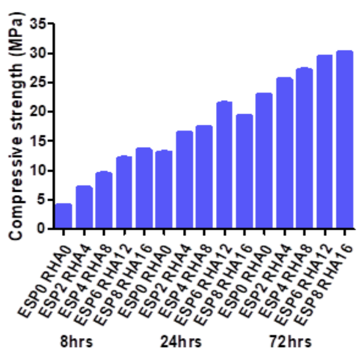

Fig: 13 Graph shows CS at 0 to 8% ESP & 0 to 16 %RHA

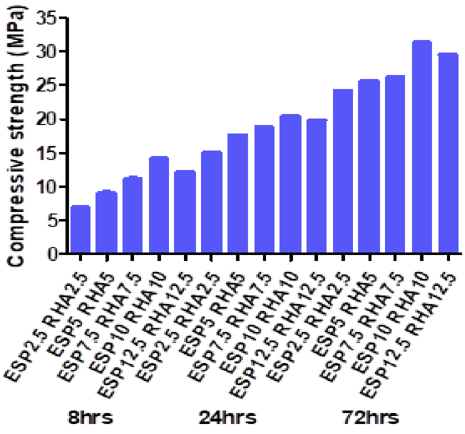

Fig: 14 Graph shows CS at 2.5 to 12.5% ESP & 2.5 to 12.5 % RHA

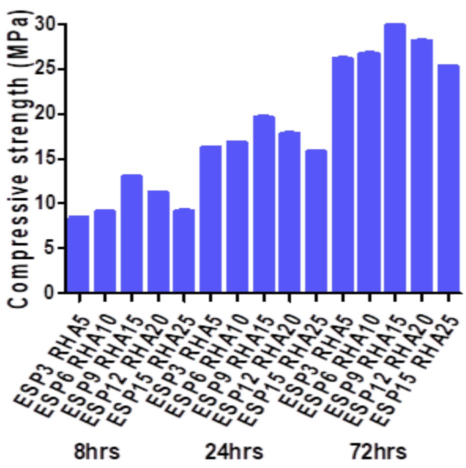

Fig: 15 Graph shows CS at 3 to 15% ESP & 5 to 25 % RHA

Conclusions

The research work has been carried out to examine the worth of RHA and ESP in oil and gas well cement as an additive to enhance compressive strength and rheological properties. The results showed that cement slurry mixed with RHA and ESP has better properties than base slurry, and following points are concluded out of this study:

1. Optimum results of CS are obtained with ESP between 8 to10% and RHA between 10 to 15 %.
2. The best replacing level of locally manufactured cement with ESP and RHA is 10% each.
3. Maximum compressive strength of 31.32 MPa has been obtained with 10% ESP and 10% RHA in 72 hours of curing time.
4. At 72 hours curing periods and test conditions of 90°C temperature and 20 MPa pressure, cement appeared to have a better strength development compared to other curing periods of 08 and 24 hours.
5. Among all three variants of cement slurry minimum gel strength obtained is 6.2 lb/100 ft^2 with ESP0% & RHA0% and maximum gel obtained is 15.4 lb/100 ft^2 with ESP10 % and RHA10% at 10 sec.
6. The RHA has been a reliable option in replacement of silica flour (SF) in applications of oil well cementing. The RHA presented silica content above 90%, being similar to the commercial SF.
7. RHA and ESP have accelerating effect hence thickening time of slurry has been decreased with rise in concentration of both additives.
8. At test conditions of 90°C temperature and 20MPa pressure, no premature gelation of cement slurry has been noticed for all cement samples prepared from RHA and ESP.

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