Investigation of the Effect of Eggshell Additive on Cement Sluryy Quality

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Abstract:- Cementing oil and gas well requires materials that ensures stability of the cased and cemented wellbore to isolate troubled zones. To achieve this job, the search for alternative material for cementing gas well has increased worldwide. Hence, it is necessary to make use of an appropriate cement programme designed with suitable additive that improves the cement bond strength, durability, resistance to abrasion on the wells life which improve quality of cement to provide zonal isolation. To protect the environment, investment, public trust and reputation, the cement plug sample porosity, permeability must be reduced, also an increase in compressive strength is needed to accomplish this technically. The research is aimed at evaluating the performance of eggshell as additive for gas well cementing operation at ambient condition. Laboratory test were conducted on a base cement sample or check plug mixed with different concentration from 30% to 70% to determine the effect on porosity, permeability and compressive strength of the cement sample. CT scan were conducted to study the composition and internal structure of the cement sample. The results showed that the 50% eggshell addition yielded the best casing integrity and should be used because it is nearly impermeable and non-porous in comparison to the base cement sample or check plug sample. An optimum concentration 50% eggshell/sandstone decreased the porosity and permeability to the barest which the aim of the study stands to achieve. The effect of eggshell and sandstone is prominent to a concentration 50%, this may be due to the equilibrium mixture present in the cement plug with the highest density of the samples obtained, and therefore increasing more than the optimum percentage of eggshell will increase cost of cementing without further improvement in performance. From the CT scan eggshell particle distribute non-uniformly in the mixture to clog the pores, helping to decrease the porosity and permeability only up to a specific quantity. At higher concentration, the result for permeability are found to be reversed whereas porosity keep decreasing. Eggshell does not have significant effect on permeability at higher concentration, while with less or mild concentration of eggshell the permeability reduced drastically. However, it is evident that addition of eggshell as additive resulted in better slurries with higher values of compressive strength greater than 500psi after 48hrs of curing which is the minimum strength before performing any perforation. After 48 hrs of curing the cement, cement sample with eggshell incorporated develop more strength by 56% to 91% increase in the compressive strength, as the concentration increases compared to the base slurry. All of the prepared cement sample exhibited a sufficient strength required for oil and gas application. Therefore, the material showed potential in making short and long-term wellbore integrity requirement. Eggshell is thought to be responsible for reducing the porosity and permeability of the cement and improving its overall strength.

Keywords:- *Cement Plug Sample, Eggshell Concentration, Porosity, Permeability, Compressive Strength, CT Scan, Zonal Isolation and Wellbore Integrity.*

I. INTRODUCTION

All through the life cycle of the well, the cement sheath is important in establishing the well integrity and zonal isolation in preventing gas migration (Kiran *et al.*, 2017). Wellbore cementing is an inseparable part of the well construction (Hao *et al*., 2016; Liu *et al*., 2015). Therefore, during drilling operation the mixture of annular cement is displaced in the annular space as a barrier between the casing string and the open hole to attain a sustainable zonal isolation and wellbore integrity. Mostly, protecting wellbore equipment from corrosion, preventing the influx of hydrocarbon gases from different permeable zones (Zhu *et al.*, 2020). Additionally, for the well to function properly, the annular cement must prevent the movement of hydrocarbon gases in the annular flow channels.(Alkhamis and imqam, 2018). However, the improper selection of anti-gas migration additive and poor design of cementing program creates migration of gases through the cement slurry, which becomes a great concern to the wellbore cementing engineers (Alyami *et al.*, 2015). Therefore, the use of anti-gas migration additive to design a suitable cement program, to improve zonal isolation is required, this requirement is to protect the environment, investment and public trust and reputation. Technically, to achieve this, the reduction in the porosity, permeability and increase in compressive strength of the cement plug sample is paramount.

This paper report the effect of eggshell as additive in cement slurry quality of porosity, permeability and compressive strength.

II. METHODOLOGY

➢ *Material*

➢ *Eggshell Preparation*

Eggshell were obtained from xyz eatery, Bayelsa Nigeria. After use the eggshell were discarded as waste. These eggshell waste were washed, membrane of the shells were removed and warm dried. These shell were crushed into powdered form in large quantity. See fig below

Fig 1 Eggshell Warm Drying

Fig 2 Powdered Eggshell

➢ *Water*

Water is a primary material required for mixing and cement hydration. 0.46% water requirement by weight of class G cement were used in accordance with API RP 10A (2019). Distilled water was used for mixing to control contamination and reduce the degree of uncertainty in the test conducted. When additive were added, the total water requirement was increased accordingly.

➢ *Class G Cement*

Commercial class G cement were used to perform the experiment. Selection of these classes were influenced by the fact that they are considered to be basic cement in the oil and gas designed to survive broad limit of well condition. The main component of class G is the clinker of the Portland cement which are responsible for the binding effect. These are mixed with gypsum (calcium sulfate) and hydraulic calcium silicate in the presence of water.

III. EXPERIMENTAL METHOD

➢ *Preparation of Cement Slurry to form Cement Plug Sample*

The laboratory test were based, mainly on the test to determine the impact of different concentration of Eggshell. All cement slurry experiment were performed in line with API –RP-10B Specification 10A requirement for material and testing for gas well cement, to prepare cement plug sample in different concentration of 0%, 30%,50% and 70%, eggshell. Vis- a- vis of 100%, 30%, 50% and 70% of Sandstone, at cement weight of 600g using the cement mixer. Laboratory test and data analyses were performed through Microsoft excel on the properties of porosity, permeability and compressive strength of the cement slurry quality. The ratio of water to cement used was 0.46. The respective density of the cement plug sample were recorded and the equipment utilized during analysis are seen in the respective fig below

Fig 3 Cement Plug Sample

Fig 4 Sandstone

Fig 5 Cement Plug Cleaning Machine/Hydrostatic Core Holder

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Fig 6 Porosimeter

Fig 8 Oven

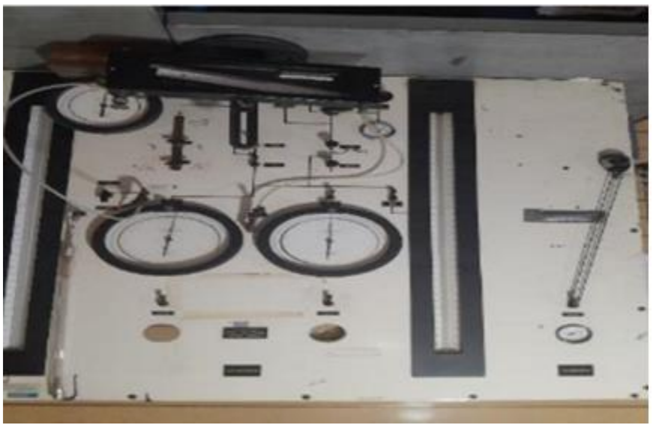

Fig 7 Permeameter

Fig 9 Compressive Strength

Table 1 Slurry Formulation Composition

Sample ID	Cement (g)	Water (ml)	Sandstone %	Eggshell %	Density (g)
1H	600	276	100%	0%	116.81
2H	600	276	50%	50%	121.83
3H	600	276	70%	30%	114.06
4H	600	276	30%	70%	113.51

IV. TEST PROCEDURE

The porosity, permeability and compressive strength measurements were carried out in the laboratory. The analyses carried out were reported in this section.

➢ *For Porosity Analysis:*

- Using a digital balance, the weight of the cement plug sample were measured.
- Cement plug sample were cured and set for 48hrs at ambient conditions
- The cement check plug or base cement sample served as the porosimeter's calibration standard.
- Cement plug formulated were measured using tape to ensure the plug is complete and to trim the edges of the core sample to make the plug look cylindrical.
- Cement Plug were encapsulated using the nickel foil to wrap the plug sample, to avoid grain losses during cleaning especially dealing with unconsolidated formation for proper identification during analysis. See fig 2
- Cement Plug were cleaned using solvent especially toluene for hydrocarbon to get freely the interconnected pore space through the hydrostatic core holder. See fig 5
- Drying and weighting stabilization of the cement plug sample were dried for 8hrs, in an oven at a temperature of 80^0c. The weighing balance was used to check the weight until it becomes stable which implies the cement plug is dried for proper analysis. Also the drying determine the kind of porosity obtained which was the effective porosity that dealt with interconnected pore spaces.
- Measure your grain volume with which grain density will be calculated. From that grain volume load the cement plug sample to the hydrostatic core holder, apply overburden pressure of 500psig. Connect helium gas to the upstream connection, use the porosimeter to flow the helium gas across the sample to obtain the pore volume to Calculate porosity Pv/Bv.

➢ *For Permeability Analysis;*

a) Drying and weighting stabilization of the cement plug sample were dried for 8 hrs, in an oven at a temperature of 80^0c. The weighing balance was used to check the weight until it becomes stable which implies the cement plug is dried for proper analysis on permeability

b) The permeameter were calibrated, by the cement check plug or base cement sample.
c) Insert the cement plug sample in the hydrostatic core holder, apply overburden pressure of 500psig. Connect the upstream and downstream connector to the permeameter, flow nitrogen gas across the sample, the pressure with which the sample is flowing, get the flow rate from the bubble tube. Use the caliper to obtain the length and diameter and viscosity of the gas which remains constants. With these data the digital permeameter will calculate the cement permeability.

➢ *For Compressive Strength Test Analysis:*

- Compressive strength of the cubes were crushed using the digital compressive testing equipment.
- The equipment measured the force it requires to destroy the sample of the cement cube, it produces it result in kilo newton.
- Before the test, the area of each sample were calculated.
- Test were carried out according to the procedure appropriated in the machine manual and reading taken.
- The load required to crush the cube in kilo newton is divided by the area of the cube is reported in mega Pascal (Mpa) for compressive strength.
- Readings were converted from Mpa to Psi for uniformity, with a conversion factor 1 KN =224.81 to obtain the results in psi.

V. RESULT

The experimental observation and result for porosity, permeability and compressive strength for the four cement plug samples obtained can be seen below from table 2 and 3 Also the computerized tomography scan images describes the structure and composition of the four cement plug sample discussed below.

Table 2 Porosity of Cement Plug

Sample ID	Sandstone %	Eggshell %	Porosity (%) @ 500psig	Grain Density g/cc	Cement plug description
1 H	100	0	45	2.65	100%sandstone,dk gry,fn-sd, wl sort,no odor,no flow
2H	50	50	35	2.56	50% sandstone / 50% eggshell,dk gry,prly sort, properly consol, no odor, no flow
3H	70	30	43	2.58	70% sandstone / 30% eggshell gry,ws ssd,no odur,no flow
4H	30	70	30	2.57	30% sandstone / 70% eggshell,gry,prly sorted, prly consol,no flow,no odor

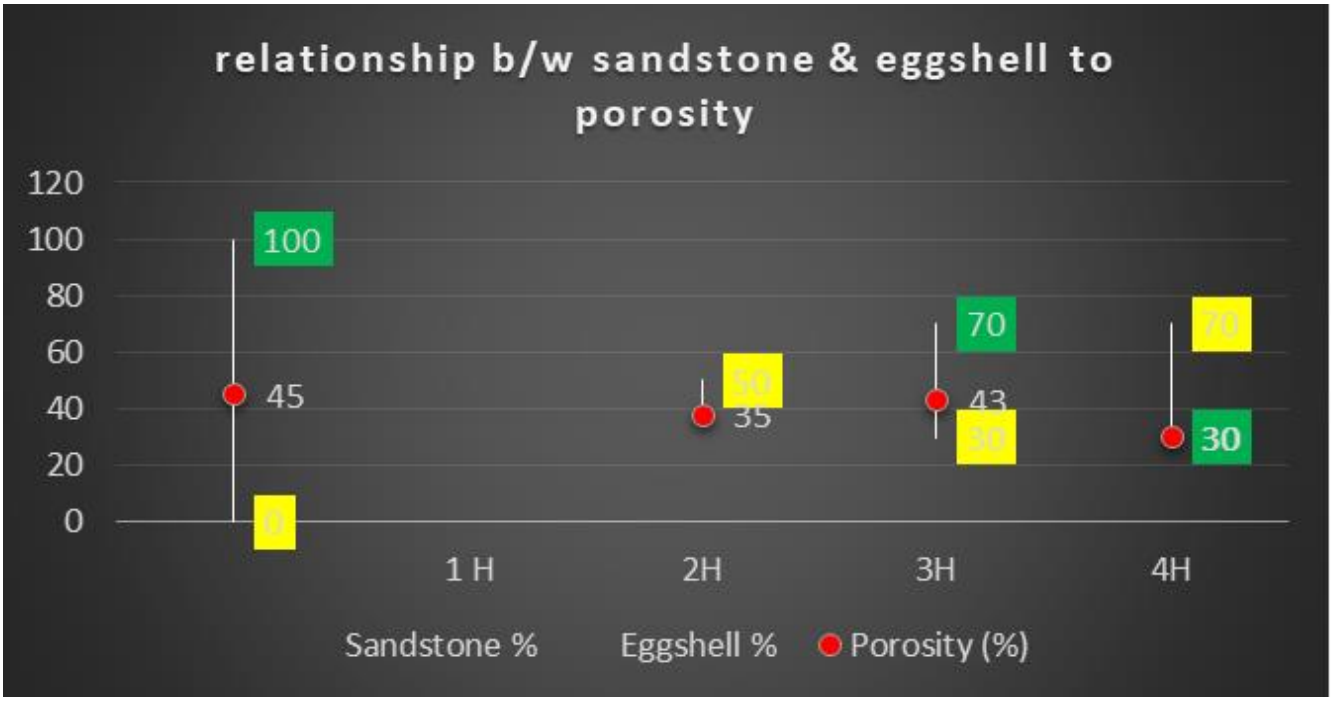

Fig 10 Porosity of Cement Plug Sample

Table 3 Permeability of Cement Plug

Sample ID	Sandstone %	Eggshell %	Absolute Permeability (md) @ 500psig	Cement plug description
1 H	100	0	0.746	100%sandstone,dk gry,fn-sd, wl sort,no odor,no flow
2H	50	50	0.104	50% sandstone / 50% eggshell,dk gry,prly sort, properly consol, no odor, no flow
3H	70	30	0.669	70% sandstone / 30% eggshell gry,ws ssd,no odur,no flow
4H	30	70	0.1319	30% sandstone / 70% eggshell,gry,prly sorted, prly consol,no flow,no odor

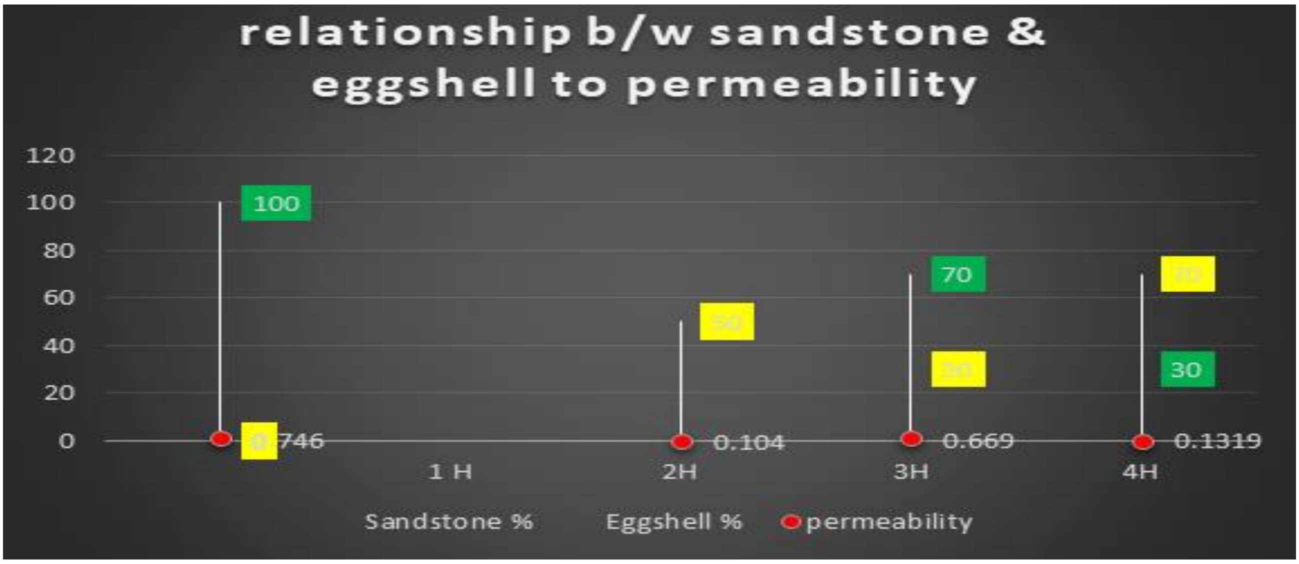

Fig 11 Permeability of Cement Plug Sample

Table 4 Compressive Strength for Cement Samples

Sample Id	Applied compressive Load (KN)	Applied compressive Load (N)	Cross sectional Area m^2	Compressive Strength (Mpa)	Compressive Strength (Psi)
1H	5.5	5500	6400	0.86	1236
2H	10	10000	6400	1.56	2248
3H	8.6	8600	6400	1.34	1933
4H	10.5	10500	6400	1.64	2360

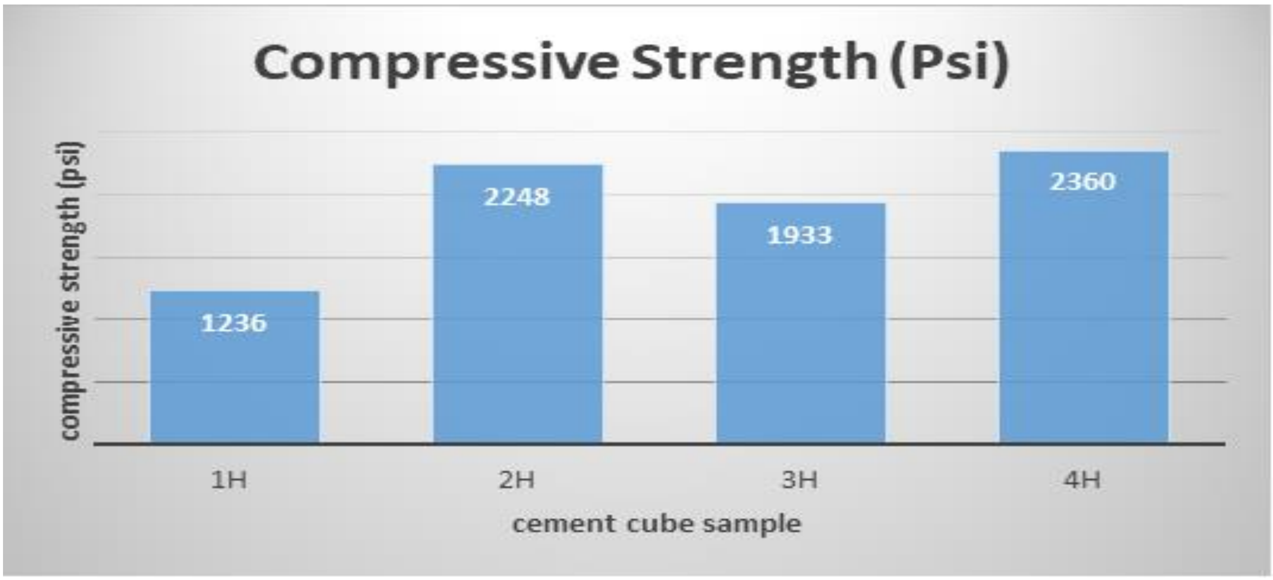

Fig 12 Compressive Strength of the Cement Plug Sample

VI. DISCUSSION

From the results obtained, it was observed that as the sandstone composition in the cement plug sample increased. i.e. for 100% and 70% sandstone, the difference in porosity was from 45% to 43% which was minimal in reducing the porosity by 4%. Also for 100% and 70% sandstone, the difference in permeability was from 0.746 to 0.669 md which is negligible, sandstone reduced the permeability by 10%.

In the sample containing 50% and 70% eggshell resulted in reducing the porosity from 35% to 30%, the eggshell reduced the porosity by 14%. For mild concentration of eggshell at 30% and 50% the permeability reduced drastically by 84%. According to finding from Ershadi *et al*, 2011 our finding are within the range of published data. While for sample containing 50% and 70% eggshell increased the permeability by 27md, this high permeability is attributed to reduced density, particle size and surface area, according to the finding of Murtaza *et al*, 2016 the observation are consistent with their findings.

Subsequently, computerized tomography CT scan images described the composition of the cement plug in different concentration. Considering the check plug which is 100% sandstone with a sample id of 1H, it was presumed to be an unconsolidated formation. Because generally sandstone usually have high porosity and permeability. The scan image showed in fig 13 the description of the cement sample having a dark grey (colour), fn sd (fine sand which increase porosity), wl sort (having particle of same sizes responsible for increase in porosity and permeability), no flow, and no odor. Further on, the second cement sample with an id of 2H having 50% sandstone and eggshell, the scan image exhibit in fig 13 the features of the cement sample with a dark grey (colour), prly sort (poorly sorted having different grain size resulting in low porosity and permeability), propyl consol (properly consolidated being compacted, hence increasing the density by reducing porosity and permeability), no flow, no odor. Also the third cement plug with a sample id of 3H containing 70% sandstone and 30% eggshell, the CT scan showed in fig 13 accounted for a grey (colour), ws ssd (well sorted sandstone, which tends to have higher porosity), no odor and no flow. Finally for the fourth cement sample having 30% sandstone and 70% eggshell with a sample id of 4H. The CT scan showed in fig 13 portray the sample with a grey (colour), prly sort (poorly sorted having different grain sizes in reducing porosity), prly consol (properly consolidated is being compacted, hence increasing density to reduce porosity), no flow, no odor. Generally according to john *et al*, 2006 finding, well sorted grains have higher porosity while poorly sorted grain reduces the porosity, also the arrangement pattern also has effect on porosity.

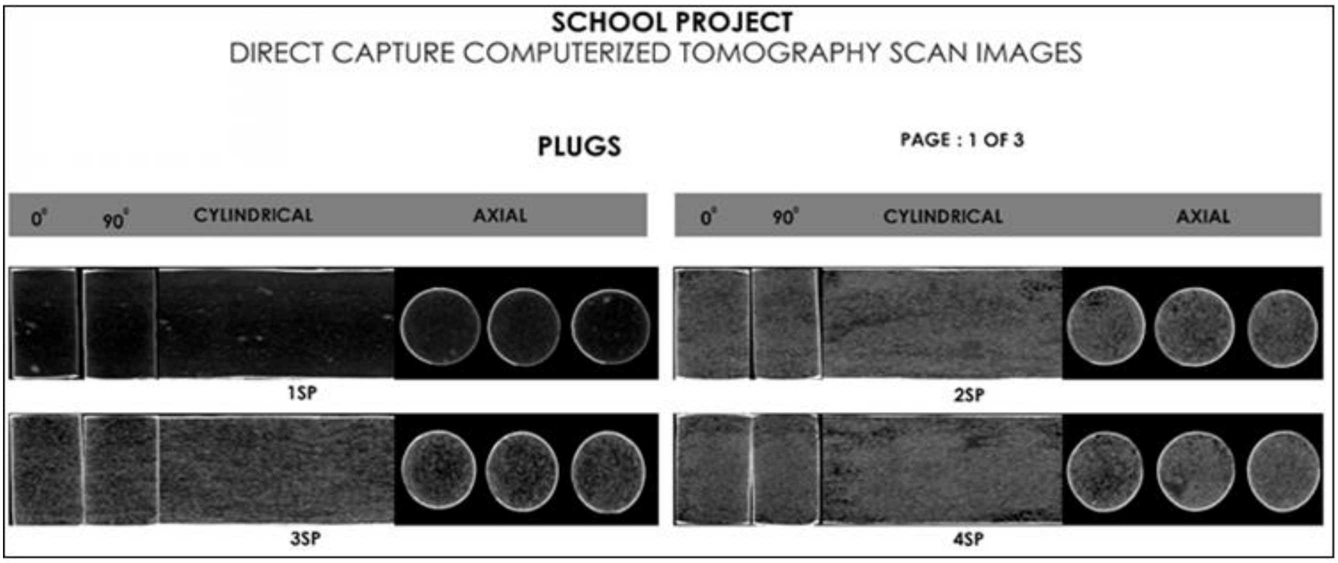

Fig 13 Direct Capture Computerized Tomography Scan Images

➢ *Effect of Eggshell on Porosity and Permeability of Cement*

The above results imply that porosity of 100% sandstone and neat cement is high for cement plug sample (1H) is 45% which is the highest porosity recorded which stands as the check plug or base cement sample. The progressive addition of eggshell causes a reduction in the porosity of well cement. Also the permeability of 100% sandstone and neat cement is relatively high with 0.746md.

From the above results, it implies that the best casing integrity, was obtained with 50% eggshell added, should be made use of because, it is almost non porous and impermeable compared to the check plug or base cement sample.

An optimum concentration 50% eggshell/sandstone decreased the porosity and permeability to the barest which the aim of the study stands to achieve. The effect of eggshell and sandstone is prominent to a concentration 50%, see fig (10 and 12). This may be due to the equilibrium mixture present in the cement plug with the highest density of the samples obtained.

- *Effect of Eggshell on the Compressive Strength of Cement*

According to Broni-Bediako et al. (2015), the compressive strength of the set cement is of the utmost importance since it commonly represents the cement's integrity, long-term bearing capability, and overall quality. According to Labibzadeh et al. (2010), higher compressive strength usually refers to lower porosity and improved durability. According to reports, a variety of cement and casing failures may be related to the cement's lack of strength, which eventually shortens the well's lifespan and compromises its structural integrity (Ridha et al., 2013).

Fig 12 illustrate the compressive strength for the three cement sample with different concentration of eggshell at ambient condition for 48hrs curing period. The results showed that the compressive strength for the base cement sample 1H, which has no eggshell (0% eggshell) was 0.86Mpa. it clear that the eggshell waste has a positive impact in the cement compressive strength, where adding 30% eggshell into the cement sample 3H improved the compressive strength to 1.34Mpa with an increase of 56% compared to that of sample 1H. Further increasing of eggshell concentration to 50% for sample 2H increased the cement compressive strength to 1.56Mpa with an increase in 81% compared with that of the base cement sample. Also for 70% eggshell concentration for sample 4H improved the compressive strength to 1.64Mpa with an increase in 91% compared to the base cement sample. However, it is evident that addition of eggshell as additive resulted in better slurries with higher values of compressive strength greater than 500psi after 48hrs of curing which according to Murtaza *et al.* (2020) is the minimum strength before performing any perforation .

All of the prepared cement sample exhibited a sufficient strength required for oil and gas application (1.37-3.45Mpa) (Huwel *at al*, 2014, Shuker *et al*, 2014). The most widely cited minimum strength needed before drill out or structurally hold a casing in place for early compressive strength is 500 psi which saves rig time and expenses, also the rig operator need higher compressive strength in order to resume drilling operation. Furthermore, the presence of eggshell is believed to be responsible for reducing porosity and permeability of the cement, thereby improving it overall strength.

VII. CONCLUSION

Eggshell has a high calcium content and good filling effect that makes it a good binding property, which enables it to close up the pore spaces interconnected, thereby reducing the porosity, permeability and improving the compressive strength of the cement slurry quality using optimum concentration. The results showed that the cement slurry mixed with eggshell waste had better properties than the check plug or base cement sample, and the following points are concluded out of this study:

From the CT scan eggshell particle distribute non-uniformly in the mixture the clog the pores, helping to decrease the porosity and permeability only up to a specific quantity. At higher concentration, the result for permeability are found to be reversed whereas porosity keep decreasing

Eggshell does not have significant effect on permeability at higher concentration, while with less or mild concentration of eggshell the permeability reduced drastically.

Eggshell is very efficient in reducing the permeability of the cement with 50% concentration, which reduced the permeability by 80% compared to the base cement sample.

Very low porosity and permeability values of the cement were noticed at an optimum concentration of 50% eggshell, with the highest density recorded. Therefore increasing more than the optimum percentage of eggshell will increase cost of cementing without further improvement in performance.

After 48 hrs of curing the cement, cement sample with eggshell incorporated develop more strength by 56% to 91% increase in the compressive strength, as the concentration increases compared to the base slurry. Therefore, the material showed potential in making short and long-term wellbore integrity requirement.

RECOMMENDATIONS

Further work should be carried out on involving broader temperature and pressure variation for different cement sample concentration in analyzing the porosity, permeability and compressive strength of the cement. Also further research should be carried out on, comparing the eggshell with other commercial anti-gas migration additive to ascertain the performance.

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APPENDIX

Table 5 Raw Data for Porosity

Sample ID	Length cm	Diameter cm	Bulk volume cm^3	Grain volume cm^3	Pore volume cm^3	Porosity ϕ
1H	6.941	3.794	78.471	44.4297	35.2679	45%
2H	7.099	3.766	71.781	47.8748	25.0738	35%
3H	6.723	3.735	73.661	44.2933	31.7997	43%
4H	7.018	3.790	79.174	44.2701	23.8057	30%

Table 6 Permeability Parameter

Sample ID	Absolute Permeability (md) @ 500psig
1H	0.746
2H	0.104
3H	0.669
4H	0.1319