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The Effect of Olive Waste on the Rheological Properties, Thickening Time, Permeability, and Strength of Oil Well Cement

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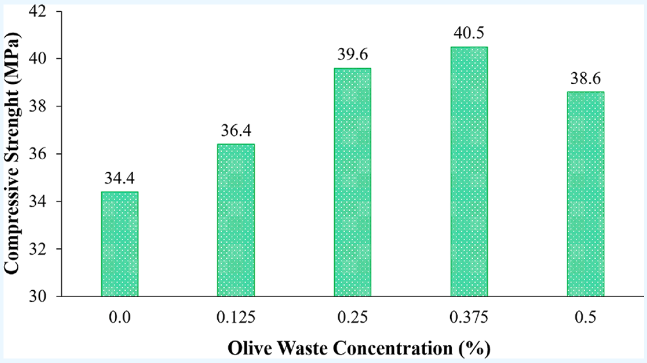
ABSTRACT: In the oil and gas industry, cementing is a very important process to maintain the stability of the well. The cement can provide an effective plug against fluid movement and at the same time supports the casing and formations. Based on the operation conditions, different types of additives are used to make the cement slurry, and incorporation of a new additive considerably affects all properties of the cement slurry and the solidified sheath. In this work, lab experiments were performed to investigate alteration of the Saudi Class G cement properties after incorporation of olive waste into the slurry, and the possibility of replacing the commercial retarder with olive waste was also studied in this work. Five samples with different olive waste content were prepared, and their rheological characteristics, thickening time, mechanical properties, and permeability were evaluated after 24 h of curing at 95 °C. The results indicated that olive waste could replace the use of a commercial retarder. The incorporation of olive waste did not affect the cement plastic viscosity, while the yield point, 10 s, and 10 min gel strengths of the cement were considerably increased with the increase in the olive waste content. The cement compressive strength was also increased with the incorporation of olive waste of a maximum of 0.375%, and the permeability decreased with the addition of a maximum of 0.25% olive waste.



1. INTRODUCTION

Oil well cementing is a vital process that plays a critical role in the oil and gas industry. The main objective of oil well cementing is to create a long-lasting and durable bond between the well casing and the surrounding geological formation, thereby preventing the migration of fluids and gases.[1−4] This is achieved by pumping a slurry of cement and other additives into the wellbore, which sets and hardens to form a seal.[1,5−8]

Cement performance and characteristics must be carefully designed to provide a very strong connection between cement and formation.[9] Failure of the cement to seal the annular area can induce many problems such as the invasion of formation fluids, fluid crossflow between different formations (underground blowout), contamination of the freshwater aquifer, and potential loss of hydrocarbon production.[10] According to Nelson and Guillot,[11] without a successful cement job, a well may never reach its full output potential. To get the most out of the well, it is crucial to build high-strength, long-lasting cement. In recent years, many additives have been developed to meet the downhole requirements.[12−15]

For the designing process, consideration of all properties of the cement is important.[16] One of the key characteristics in designing cement slurry is to provide good rheological properties that assist in improving the displacement efficiency. The workability of cement slurry is highly affected by its rheological properties, which are a function of the homogeneity of cement additives in terms of concentration, quantity, and quality.[17] Additionally, it was found that the distribution and concentration of solids in cement slurry have a major effect on the rheology behavior of cement slurry.[18] Also, for efficient mud cleanup, turbulent flow is required, which could be achieved by adjusting the rheology behavior of cement slurry.[19]

In addition to the importance of rheological properties, cement sheaths should ensure well stability which usually has long-term requirements and is affected by the cement's mechanical integrity and strength.[4,20]

Nowadays, it has become very important to recycle and reuse industrial and agricultural materials to meet environmental regulations. Olive waste is one of the industrial wastes produced from the olive oil extraction process. There are many olive oil producing countries around the world such as Jordan, Italy, Spain, Turkey, and France, countries where a huge

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amount of olive waste is produced. Many studies evaluated the impact of olive waste ash as a complementary additive in concrete for the construction industry, where it showed a high potential of improving the properties of concrete.[21−23] Therefore, instead of dumping the olive waste in a sanitary landfill, it could be beneficial in the oil cementing industry.

Dahim et al.[24] examined the potential of using olive waste ash in concrete by substituting different proportions of cement with ash. The findings demonstrated that olive waste ash is a viable option to improve the concrete strength and enhance its durability, as including olive waste ash will reduce the water-to-cement ratio in a mixture of concrete and, at the same time, fill the pores in concrete structure material.

In the same context, Al-Akhras[25] examined the effect of silica-alkali on the properties of concrete that includes olive waste in its composition. The results illustrated an increase in resistance with an increase in the percentage of olive waste.

In another study, the influence of temperature on the cement's compressive strength was investigated. Al-Akhras et al.[26] conducted lab experiments on concrete with different percentages of olive waste ash. The results indicated that adding olive waste improved the concrete properties at elevated temperatures.

Recently, Mahmoud and Elkatatny[27] demonstrated that olive waste can enhance the carbonation resistance of oil well cement when exposed to CO_2-rich brine for 20 days of exposure. Incorporating 0.1% by weight of cement (BWOC) decreased the carbonation depth of the cement from 1469 μm (in samples without olive waste) to 1269 μm (in samples with 0.1% BWOC).

The objective of this study is to assess how altering the concentration of olive waste affects various properties of Saudi Class G oil well cement, including thickening time, compressive strength, rheological properties, and permeability. Additionally, the feasibility of using olive waste as a substitute for a commercial retarder was examined.

2. MATERIALS AND METHODOLOGY

2.1. Materials. According to the American Petroleum Institute (API) standards,[28,29] five cement samples were prepared to evaluate the effect of olive waste content on cement properties. As outlined in Table 1, the sample comprises a Saudi Class G cement, a dispersant, a defoamer, a fluid loss additive, and water. All additives in this table are in grams. As indicated in Table 1, the base sample (i.e., the sample with no olive waste) was prepared with 4.8 g, 0.8% by weight of cement BWOC, of a commercial retarder. The other samples were prepared with different olive waste contents (between 0.125 and 0.5% BWOC), and all of them have no commercial retarder.

Table 1. Cement Samples Composition (All Additives in Grams)

	olive waste concentration (% BWOC)				
component	0	0.125	0.25	0.375	0.5
Saudi class G cement			600		
commercial retarder	4.8			0	
dispersant			6		
fluid loss additive			4.8		
defoamer			28.2×10^{-7}		
water			264		
olive waste	0	0.75	1.5	2.25	3.0

Table 2 presents the phase composition of Saudi Class G cement, while Table 3 depicts the mineralogical composition of the olive oil waste used, which is a byproduct of the olive oil extraction process. As shown in Table 3, the olive waste is primarily composed of sylvite with a smaller percentage for tridymite and quartz. Furthermore, Figure 1 displays the particle size distribution of both Saudi Class G cement and olive waste. It reveals that the D_{50} of Saudi Class G cement is 21.3 μm, whereas that of olive waste is 57.0 μm.

Table 2. Phase Composition of the Saudi Class G Cement

element	proportion (wt %)
C_3A	<1
C_2S	15
$C_4AF + 2C_3A$	18
C_3S	65

Table 3. Olive Waste's Mineralogical Composition

mineral element	quartz	tridymite	sylvite
concentration by weight (%)	10.3−14.7	16.2−22.3	65.4−73.6

2.2. Methodology. Following the compositions listed in Table 1, cement slurries were prepared and poured into metallic molds of varying sizes, depending on the intended test. The molds were subsequently submerged in a water bath and cured at 95 °C for 24 h. After this initial day of curing, the properties of the cement were evaluated using the procedure outlined in the following sections.

2.2.1. Rheological Properties Measurement. To evaluate the rheological characteristics of the cement slurry, including plastic viscosity, yield point, 10 s gel strength, and 10 min gel strength, a rheometer was utilized at a temperature of 95 °C and atmospheric pressure. The API standard API[28] was followed for the measurement procedure.

2.2.2. Thickening Time Measurement. The consistometer was used to measure the thickening time of the cement slurry under a temperature of 95 °C. The reported thickening time is the duration required by the samples to have a consistency of 100 Bearden consistency (Bc) units. The temperature at the start of all experiments was 25 °C, which was then increased within 15 min to reach 95 °C, which was then maintained until a cement slurry consistency of 100 Bc was reached.

2.2.3. Compressive Strength Measurements. To measure the compressive strength of the samples, cylindrical samples with a diameter of 1.5 in. and a length of 3.0 in. were subjected to scratch testing. During the scratch test, a scratch with 0.25 mm depth and 1.0 cm width was made along the length of the sample to measure its resistance for scratch generation and strength. After 24 h of curing at 95 °C, eight scratches were made in each sample. Then, the compressive strength for each sample was considered as the average of the eight measurements.

Since there has been no industrial standard for a scratch test until now, in this part of the study, the compressive strength was also measured using the crushing test conducted on cubical samples of 2.0 in. edges following the ASTM standard.[30] The crushing test was conducted on three specimens representing every cement formulation considered

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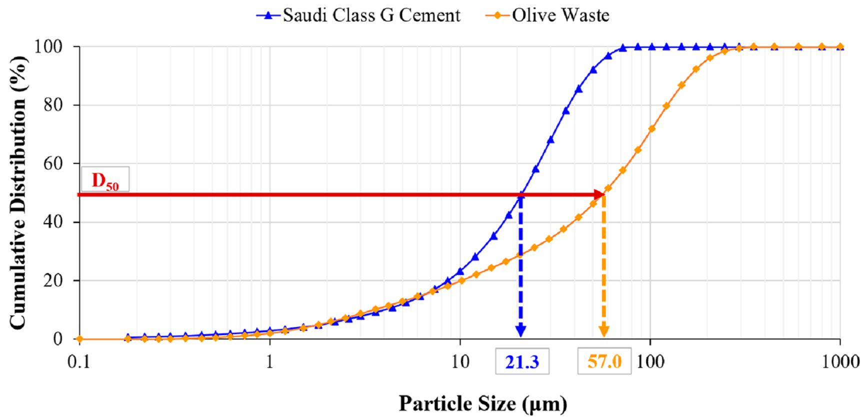

Figure 1. Distribution of the particle size of Saudi Class G cement and olive waste.

in this study, and the average of the three measurements was considered as the compressive strength for that cement formulation.

2.2.4. Permeability Measurement. To conduct the permeability test, cylindrical samples with 1.5″ diameter and 0.9″ length were used for permeability measurements. After curing the samples at 95 °C, the permeability measurement was performed under atmospheric conditions. The tests were conducted following the methodology illustrated by Sanjuán and Muñoz-Martialay,[31] which is based on the Hagen–Poiseuille law. A backpressure of 1000 psi was used during the measurements, which were conducted using nitrogen.

3. RESULTS AND DISCUSSION

3.1. Rheological Properties. The rheological characteristics of the five cement samples prepared in this study were studied; this includes the plastic viscosity, yield point, 10 s, and 10 min gel strength. Figure 2 and Figure 3 compare the changes in the rheological properties of the cement slurries with the increase in the olive waste content.

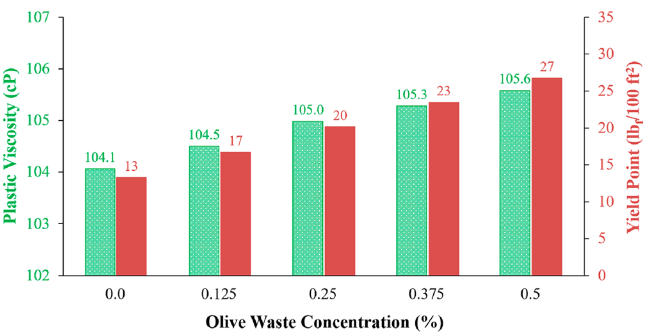

Figure 2. Change in plastic viscosity and yield point of the five cement slurries under study.

As shown in Figure 2, the addition of the olive waste did not show a noticeable change in the plastic viscosity, where the base cement slurry (i.e., the sample without olive waste) has a plastic viscosity of 104.1 cP, and the highest plastic viscosity was 105.6 cP, which was noticed after incorporation of 0.5% olive waste. This minor increase in the plastic viscosity confirmed that the addition of olive waste will not lead to any restriction on cement pumpability at the surface.

Figure 2 illustrates the evaluation of the yield point for the cement slurries. The incorporation of olive waste resulted in a notable difference in the yield point of the cement slurries. The base slurry exhibited a yield point of 13 $lb_f/100\ ft^2$, while the yield point significantly increased when olive waste was added. The samples containing 0.5% olive waste demonstrated a doubled yield point compared with the base slurry. This increase in the cement yield point is good since it helps in enabling the cement slurry to prevent any kind of solids segregation and hence ensure the formation of a homogeneous cement sheath when the cement is solidified.

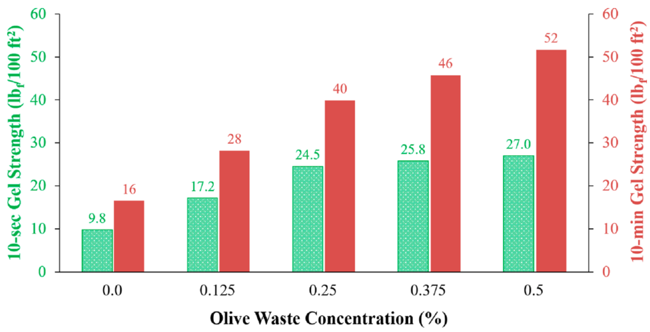

Figure 3. Change in the 10 s and 10 min gel strengths of the cement slurries with the olive waste concentration.

The gel strength of the cement slurries was also evaluated, as shown in Figure 3. As we can see in this figure, both 10 s and 10 min gel strengths of the cement samples were increasing with the increase in the olive waste content. Although a high increase in the gel strength is not recommended since high injection pressure will be required at the surface to start the circulation of the slurry if the pumps are stopped for a specific time, this property is also necessary to help the slurry carrying large solid particles when circulation is stopped. As indicated in Figure 3, the base slurry exhibits a gel strength of 9.8 and 16 $lb_f/100\ ft^2$ at 10 s and 10 min, respectively. The addition of the olive waste increased both 10 s and 10 min gel strengths. The sample containing 0.5% olive waste demonstrated the highest gel strength, with a 10 s gel strength of 27 $lb_f/100\ ft^2$ and a 10 min gel strength of 52 $lb_f/100\ ft^2$.

3.2. Thickening Time Results. The thickening times of the five samples under study were evaluated using the consistometer. Figure 4 compares the variation of the thickening time with the olive waste concentration. The results in this figure show that the addition of olive waste noticeably increased the thickening time for the cement slurry. A neat cement sample was additionally prepared without any

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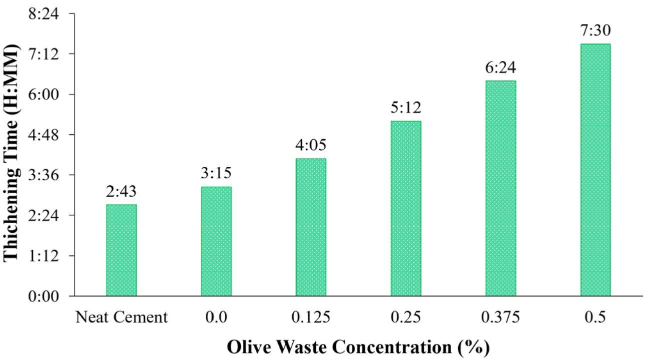

Figure 4. Variation of the thickening time with the olive waste concentration. The reported time represents the time needed for every sample to have a consistency of 100 Bc units.

incorporation of olive waste or a commercial retarder, and as reported in the figure it has the shortest thickening time of 2 h and 43 min. The base sample with 0% olive waste has a thickening time of 3 h and 15 min; as mentioned earlier, this sample incorporated 0.8% of a commercial retarder. The incorporation of 0.125% of olive waste (with no commercial retarder) increased the thickening time to 4 h and 5 min. The thickening time was then increased steeply with the addition of olive waste and reached 7 h and 30 min. All samples with olive waste do not have a commercial retarder.

The results of thickening time measurements indicate the possibility of using olive waste as an organic additive to increase the thickening time. This will help in modifying the properties of the cement using a low-cost waste material and at the same time allows time to find a safe place to dump this olive waste.

3.3. Compressive Strength.

Alteration of the compressive strength with olive waste addition is summarized in Figure 5.

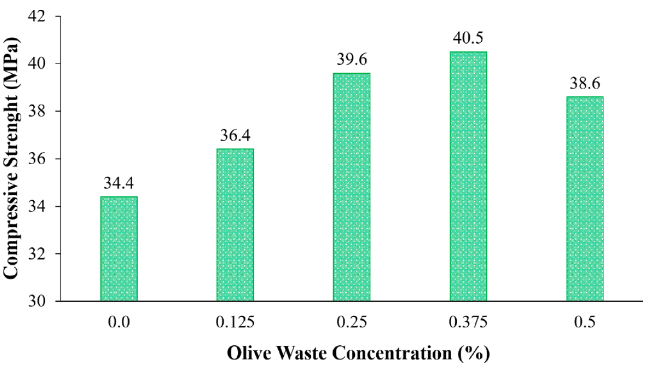

Figure 5. Change in the cement matrix compressive strength with the olive waste concentration.

The values reported in this figure are the average of three measurements performed on specimens representing every sample. As shown in Figure 5, the incorporation of the olive waste is good for compressive strength increase. The base sample (i.e., sample with no olive waste) has a compressive strength of 34.4 MPa, and the compressive strength increased with the incorporation of olive waste to 0.375% where the samples with 0.125, 0.25, and 0.375% BWOC olive waste have compressive strengths of 36.4, 39.6, and 40.5 MPa, respectively. The sample with 0.375% BWOC has a compressive strength that is 17.7% more than that of the base sample strength. Although the addition of 0.5% BWOC olive waste to the cement slurry led to a reduction in the compressive strength to 38.6 MPa, which is less than that for the sample with 0.375% olive waste, this sample still has a compressive strength which is 12.2% greater than that of the base sample.

The compressive strength was also measured using the crushing machine and following the ASTM[30] standard to confirm the accuracy of the scratch testing, which has no industrial standard. The result of this comparison is summarized in Table 4, which shows a maximum difference of 4.2% between the two measurement methods.

Table 4. Comparison of the Compressive Strength Measurements by Scratch Test and Crushing Machine

	olive waste concentration (%BWOC)				
	0	0.125	0.25	0.375	0.5
UCS from scratch test (MPa)	34.4	36.4	39.6	40.5	38.6
UCS from crushing test (MPa)	33.0	36.9	39.4	41.4	39.9
difference (%)	4.2	1.4	1.3	2.2	3.3

3.4. Permeability.

Figure 6 displays the permeability alteration with the variation in olive waste content. There were

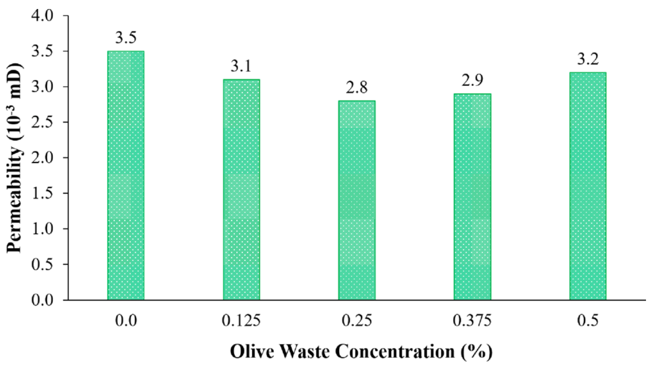

Figure 6. Change in the cement matrix permeability with the olive waste concentration.

two observed trends of permeability change with the addition of olive waste, where the permeability decreased with incorporation of up to 0.25% olive waste; beyond this concentration the permeability was increased continuously. The permeability of the base cement was 0.0035 mD, it decreased to 0.0031 mD for the sample with 0.125% olive waste. The incorporation of 0.25% olive waste reduced the permeability to 0.0028 mD, a reduction of 20.0% compared to the permeability of the base sample. Although, an increasing trend of permeability values was observed when 0.375 and 0.5% of olive waste were added. The permeability of 0.5% OW is still smaller than that of the base cement sample permeability by 8.5%.

4. CONCLUSIONS

This study examined how the addition of olive waste affected the properties of Saudi Class G oil well cement as well as the feasibility of substituting a commercial retarder with olive waste. The following observations can be made based on the obtained results:

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- The usage of olive waste could increase the thickening, and it was possible to replace the use of one of the commercial retarders. This opened the opportunity to use it as a retarder.
- Olive waste has a negligible effect on the plastic viscosity of cement slurry. Though, it could increase the yield point and gel strength of the cement slurry.
- The addition of olive waste improved the compressive strength of the cement matrix, which is important to ensure zonal isolation and provide the required support for the casing weight and the drilled formations.
- Incorporating olive waste at concentrations lower than 0.375% decreased the permeability of cement specimens, thereby enhancing the cement sheath's sealing effectiveness.

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Author Contributions

Conceptualization, A.A.M. and S.E.; methodology, A.A.M.; experimental, A.A.; validation, A.A.M., M.A., and S.E.; formal analysis, A.A.M. and S.E.; writing—original draft preparation, A.A.; writing—review and editing, A.A.M. and M.A.; visualization, A.A.M.; supervision, A.A.M.

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