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IMPROVEMENT OF BLENDED CEMENT CHARACTERISTICS AS POSSIBLE ALTERNATIVE FOR OIL WELL CEMENT

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ABSTRACT

The paper presents the results of the laboratory studies on locally produced blended cement as an oil well cement. The results show that the blended cement has less free water, less fluid loss, better strength development but shorter thickening time than G cement. In addition. The results also show that there is a great increase in strength development by adding the palm oil fly ash, however there will be a decrease in strength if more than 15 % of the fly ash is added to the cement. The cost per bag of blended cement is cheaper and there will be a saving of about 48 % of the cement material cost if the blended cement is used to cement an average oil well at 8,000 ft depth. In general, the blended cement showed a better results than G cement as the water cement ratio been varied even though as the ratio increases the free water and fluid loss also increases. Blended cement proves to be the alternative choice for the replacement of G cement in cementing job, particularly for the shallow well due to the shorter thickening time.

BACKGROUND

In cementing an oil well, the cement slurry is pumped through the casing and then back up through the small annular space between the borehole wall and the casing. Therefore, the cement slurry must remain as a pumpable fluid until it is in its final setting place regardless of the temperature and pressure to which it is subjected or to the time required. At the setting depth, the cement slurry should set hard quickly and develop sufficient strength to withstand the tensile and compressive stresses in the borehole and should also form a permanent and enduring bond between the formation rock and the casing.[1] The set cement has to seal off the undesirable formation water, to protect the casing from external corrosion, to provides the strength and the reinforcement to the casing, and to provides zonal isolation. In order to achieved these requirements, additives were used with the cement to produce a satisfactory cement slurry performance for a given well conditions, since we have no control to the temperature and pressure factors.

Cement has been considered as a mixture of the oxides calcium (CaO), alumina (Al_2O_3), silica (SiO_2), magnesium (MgO), iron (Fe_2O_3), potassium (K_2O) and sodium (Na_2O). During heating process to the temperature of about 2700 °F, these oxides combine to form calcium silicates and aluminates which commonly referred to as a clinker.

In Malaysian oil and gas industry, the class G cement is being used during the oil and gas wells cementing operation and this cement is imported from other countries, like Australia, Thailand, Indonesia and Singapore through foreign cementing service company. Therefore, affords have been made to study the potential of locally produced blended cement to replace the class G cement. In order to be able to be used as an oil well cement, the locally produced blended cement must comply in terms of their chemistry and physical properties to the standards set by the American Petroleum Institute (API), as specified in API Specification 10, Specification For Materials and Testing For Well Cements.[2]

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EXPERIMENTAL WORK

Locally produced blended cement and imported class G cement were studied. Laboratory experiments were carried out on dry cement powders, cement slurry and hard set cement. The chemical analysis was done by wet test method, as described by the ASTM C-114. The cement slurry and specimen preparation, and the physical properties were conducted by closely followed the API Specification 10. The physical properties test include the compressive strength, fluid loss, thickening time and free water. A simple economic analysis was also carried out to understand the market need.

RESULT AND DISCUSSION

CHEMICAL ANALYSIS

As shown by Table 1, the percentages of the oxides minerals and the chemical compounds for the blended and class G cement are very much different, particularly aluminium oxide, calcium oxide, silicon dioxide, and all chemical compounds. The differences involved between them were due to the composition and percentage of raw materials used during the manufacturing process. These differences will have an effect to the performance of the cement.

COMPRESSIVE STRENGTH

Results of the compressive strength test with different percentage of additives and curing period are shown in Table 2. In general, the blended cement has the higher strength then the class G cement. The blended cement has shown an increased in strength development due to the fly ash has played an important role in providing the strength to the cement with the formation of extra cementitious material of tricalcium silicate hydrate. High content of tricalcium aluminate in the blended cement then in the class G cement, a very fast rate of reaction during hydration and a very fast setting time explains why the blended cement has higher compressive strength then class G cement. The compressive strength development progress for each type of cement is clearly shown in Figure 1.

With retarder and fluid loss additives, both types of cement produced less compressive strength as the amount of an additive increased in the slurry. But, the blended cement gives a better strength development as compared to the class G cement. Besides the delaying effect of cement to set cause by an additive, the slow pozzolanic activities which took place between the calcium hydroxide that is the product of cement hydration process has helped in developing the extra gel of tricalcium silicate hydrate which occupied the pores and contribute to the strength development of the cement. The profile of compressive strength development due to an additive is shown in Figure 2 and 3, respectively.

Table 3 shows the results of blended cement compressive strength when the palm oil fly ash was added to the neat cement. As shown in Figure 4, the blended cement compressive strength increases as the amount of palm oil fly ash added to the cement increases up to 15 %. The pozzolanic reactivity provided by the ash has helped in developing the extra gel of tricalcium hydrate which contribute to the strength development. A reduction in cement strength can be noticed when 20 % or more of the palm oil fly ash is added but the strength is still higher then the neat cement strength. Further increase the amount of fly ash content to 25 % will results in a further reduction of the cement strength, i.e below the strength of the neat cement. This is due to the fact that too much pozzolanic activities which does not contribute further to enhance the cement strength but to reduce the strength.

FLUID LOSS

Results of fluid loss tested at 52 °C circulating temperature and 1000 psi differential pressure with different percentage of the additives are shown in Table 4. From the table, it can be seen that the blended cement released less fluid loss as compared to the class G cement. It proves that, during the cement reaction and with the existing of water, fine particles of fly ash will react with the excess calcium oxide and calcium hydroxide produced during the early reaction stage to form an additional cementitious material of tricalcium silicate hydrates which will filled the existing pores with the cement and thus will reduce the number of pores, and consequently will reduce the permeability of the cement.[3] With higher content of tricalcium aluminate in the blended cement, it will react at a faster rate during the hydration process, which will produce less fluid loss as compared to class G cement, which in constrast contain less tricalcium aluminate.[4]

Table 4, Figure 5 and 6 also show that the volume of fluid loss is decreasing as the amount of mixing additives are increasing, for both cements. However, the blended cement gives less or better fluid loss as compared to the class G cement. This is due to the additive presents in the cement slurry and also due to the part played by the fine fly ash in occupying the micro pores and it's pozzolanic reactivity in reducing the permeability of the cement, therefore reduced the amount of fluid loss.

THICKENING TIME

Table 5 shows the results of the thickening time of each cement tested at the simulated reservoir conditions, i.e. at 8,000 ft depth and 52 °C temparature. It was found that the blended cement will set at a shorter time then the class G cement. The blended cement which has higher tricalcium aluminate content (6.28%) will take a shorter period of time to set as compared to the class G cement which has less tricalcium aluminate content (1.48%), since higher content of tricalcium aluminate will have a higher reaction rate during the hydration process and therefore, will set at a faster time.

Table 5, Figure 7 and 8 also show that there is an increased in thickening time as the amount of the additives are added to the cement, with the blended cement still has less thickening time as compared to the class G cement. This is due to the pozzolanic reactivity has caused the blended cement to set a little bit faster. Therefore, the class G cement proved to has a better pumping capability as compared to the blended cement. Although the pumping time for the blended cement is less then the class G cement, but the time clocked is reliable, since the API standard for the class G thickening time is in the range of 90 to 120 minutes. Therefore, the blended cement can be considered suitable for the cementing job less then 5 hours, i.e., for the shallow well.

FREE WATER CONTENT

The results of free water is shown in Table 6. From the table, it is clear that the blended cement gives less free water then the class G cement, both below API Standard for free water content of 3.50 ml maximum. The different in tricalcium aluminate content in each cement will result in different rate of reaction and consumption of water, and will effect the amount of free water produced by the cement, respectively.
Table 6, Figure 9and 10 also show that the amount of free water produced by both cements decreases as the amount of additives increases, but the blended cement still produced less free water as compared to the class G cement. When the amount of additives used comes to 1.0 % or more, there is no free water produced. The fly ash content in the blended cement delayed the reaction of cement with water by filling the pores between the cement grains and thus traps some of the water. In addition, some of the water is consumed by the fly ash to disintergrade and react with the calcium hydroxide to produced cementitious material, therefore the cement set with less free water

EFFECT OF WATER CEMENT RATIO

Results of the fluid loss and free water tests with different water cement ratios are shown in Table 7. From the table, it can be seen that the blended cement still produced less fluid loss and free water as compared to the class G cement, even though the fluid loss and free water volume for both cements will increases as the water cement ratio increases, as shown in Figure 11 and 12, respectively.

ECONOMIC ANALYSIS

From a simple economic analysis shown in Table 8, its cheaper to use locally produced blended cement for the cementing operation of an average oil well of 8,000 ft depth. Based on the current selling price of the cement, there will be a saving of RM 5.70 per foot or 48 % of the total cost for cement material if the locally produced blended cement is used for the oil well cementing operation.

CONCLUSION

The results of the study had shown that the locally produced blended cement has less free water, less fluid loss, better compressive strength development but shorter thickening time than the class G cement. The thickening time for the blended cement is still within the API specification. The results also proved that the blended cement is compatible to be used with the existing retarder and fluid loss agent. The palm oil fly ash can be used to improve the blended cement compressive strength, with the highest strength can be achieved when 15 % of the ash is added to the neat cement. The strength will be decreased if 20 % or more fly ash was added to the cement.

In general, the locally produced blended cement have the properties which are within the range of API Specification and therefore is suitable for the application in the oilwell cementing operations, particularly for the five hours or less cementing operation.

REFERENCE

1 John Bensted, "*Cement With a Specific Application - Oilwell Cements*", World Cement, March 1987, page 72-79.

2. API Specification 10, *Specification For Materials and Testing For Well Cements*, American Petroleum Institute, USA, July 1, 1991.

3. R. Helmuth, *Fly Ash in Cement and Concrete*, Portland Cement Association, Research and Development Laboratories, U.S.A.

4. N.C. Ludwig, *Portland Cements and Their Application in the Oil Industry*, Drilling and Production Practices, API, USA, 1953.

Table 1. Chemical Composition of Blended and Class G Cements

OXIDE COMPONENT	CLASS G CEMENT (%)	BLENDED CEMENT (%)
Calcium oxide	65.13	53.67
Silicon dioxide	22.15	27.81
Iron oxide	4.72	3.48
Aluminium oxide	3.57	8.33
Magnesium oxide	0.71	0.60
Sulphur trioxide	2.18	2.45
Potassium oxide	0.35	0.43
Etc	1.13	2.34
CHEMICAL COMPOUND	CLASS G CEMENT (%)	BLENDED CEMENT (%)
Tricalcium silicate	59.7	44.00
Dicalcium silicate	18.81	14.42
Tricalcium aluminate	1.48	6.28
Tetracalcium aluminoferite	14.37	9.52

Table 2. Compressive Strength at Simulated Reservoir Conditions

Additive (%)		Compressive Strength (psi)							
		8 hours		1 day		3 days		7 days	
Retarder	Fluid Loss	Class G Cement	Blended Cement	Class G Cement	Blended Cement	Class G Cement	Blended Cement	Class G Cement	Blended Cement
0.00	0.00	1800	1850	2760	2980	3270	3930	-	-
0.20	0.00	1750	1820	2500	2650	3100	3300	3200	3450
0.50	0.00	1550	1660	2320	2510	2950	3190	3150	3310
0.70	0.00	1010	1250	1850	2150	2450	2920	2980	3120
1.00	0.00	-	-	980	1170	1260	1490	1410	1700
0.00	0.50	1800	1920	2610	2800	3450	3780	3340	3610
0.00	1.00	1720	1810	2500	2650	3290	3450	3160	3300
0.00	1.50	1540	1660	2210	2360	3120	3280	3010	3180
0.00	2.00	1310	1410	2020	2180	3050	3190	2910	3090

Table 3. Compressive Strength of Blended Cement with Various Palm Oil Fly Ash Amount

Palm Oil Fly Ash (%)	Compressive Strength (psi)			
	8 hours	1 day	3 days	7 days
0	1850	2980	3930	4700
5	1910	3190	4060	4910
10	2070	3460	4440	5350
15	2240	3730	4820	5800
20	2130	2870	4440	4970
25	1680	2820	3800	4440

Table 4. Fluid Loss Tested at 52 °C and 1000 psi pressure differential

Additive (%)		Fluid Loss Volume (ml)	
Retarder	Fluid Loss	Class G Cement	Blended Cement
0.00	0.00	680	630
0.20	2.00	75	71
0.50	2.00	82	77
0.70	2.00	90	81
1.00	2.00	100	90
0.20	1.50	163	120
0.50	1.50	173	138
0.70	1.50	182	158
1.00	1.50	200	173
0.20	1.00	342	310
0.50	1.00	354	327
0.70	1.00	368	340
1.00	1.00	284	358
0.20	0.50	638	612
0.50	0.50	643	620
0.70	0.50	670	634
1.00	0.50	688	650

Table 5. Thickening Time of the Tested Cement

Additive (%)		Thickening Time at 100 Bc (minutes)	
Retarder	Fluid Loss	Class G Cement	Blended cement
0.00	0.00	112	102
0.20	0.00	168	150
0.50	0.00	296	202
0.70	0.00	382	219
1.00	0.00	-	306
0.00	0.50	167	142
0.00	1.00	195	177
0.00	1.50	246	190
0.00	2.00	272	195

Table 6. Free Water Test

Additive (%)		Free Water Content (ml)	
Retarder	Fluid Loss	Class G Cement	Blended Cement
0.00	0.00	1.37	0.72
0.20	0.50	1.30	1.00
0.50	0.50	0.86	0.81
0.70	0.50	0.80	0.70
1.00	0.50	0.40	0.25
0.20	1.00	0.26	0.20
0.50	1.00	0.00	0.00
0.70	1.00	0.00	0.00
1.00	1.00	0.00	0.00

Table 7. Effect of Water Cement Ratio to the Cement Physical Properties

Water Cement Ratio (%)	Fluid Loss Volume (ml/30 minutes)		Free Water Volume (ml)	
	Class G Cement	Blended Cement	Class G Cement	Blended Cement
38	25	14	0.20	0.10
43	28	22	0.32	0.25
48	36	30	0.42	0.30
53	48	35	0.78	0.52
56	59	45	1.18	0.88

Table 8. Simple Economic Analysis for Cement Requirement

Cement Type	Well Depth (ft)	Average Cement Required (sack)	Average Cement Price (RM/sack)	Total cement cost (RM)
Class G cement	8,000	4267	22.30	95,154.10
Blended cement	8,000	4267	11.60	49,497.20

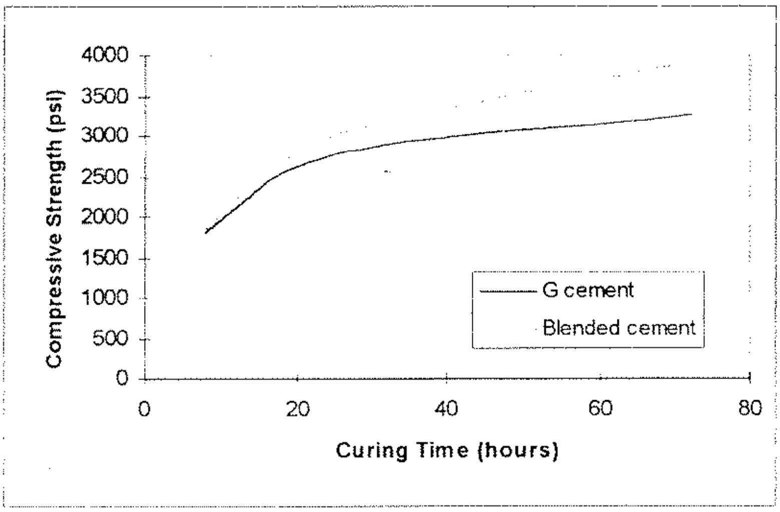

Figure 1. Compressive Strength Profile

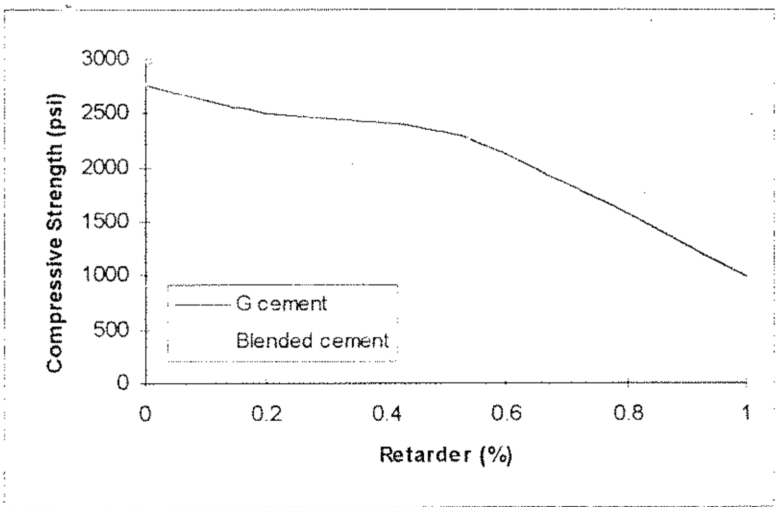

Figure 2. Effect of Retarder to the Compressive Strength (1 day)

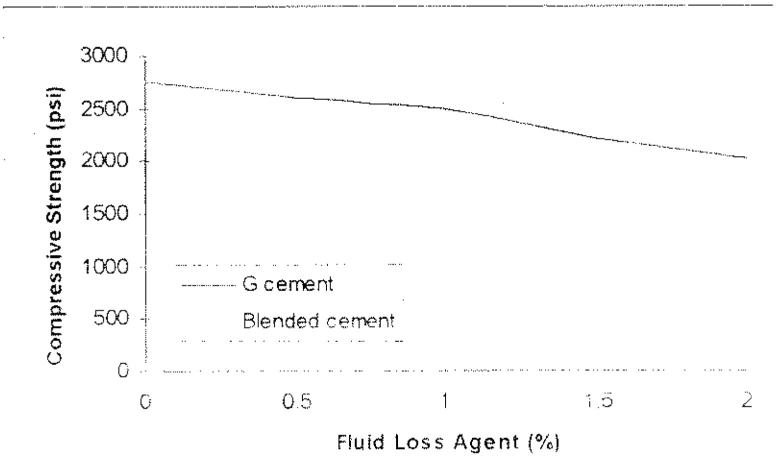

Figure 3. Effect of Fluid Loss Agent to the Compressive Strength (1day)

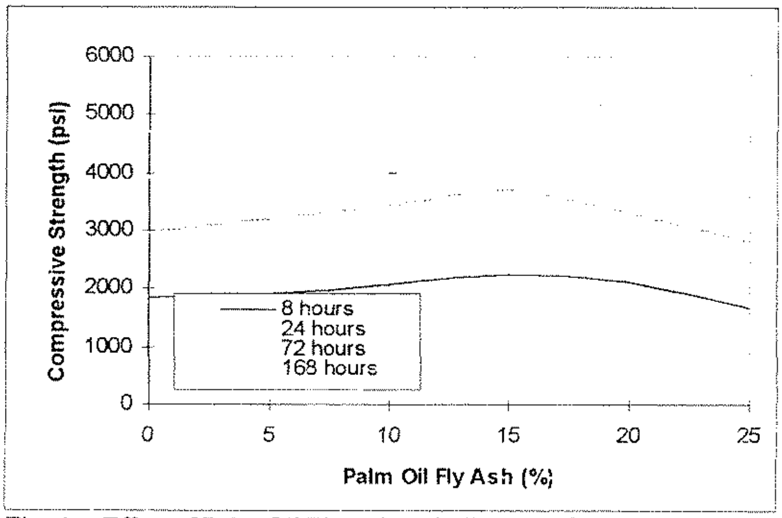

Fig. 4. Effect of Palm Oil Fly Ash to the Blended Cement Compressive Strength

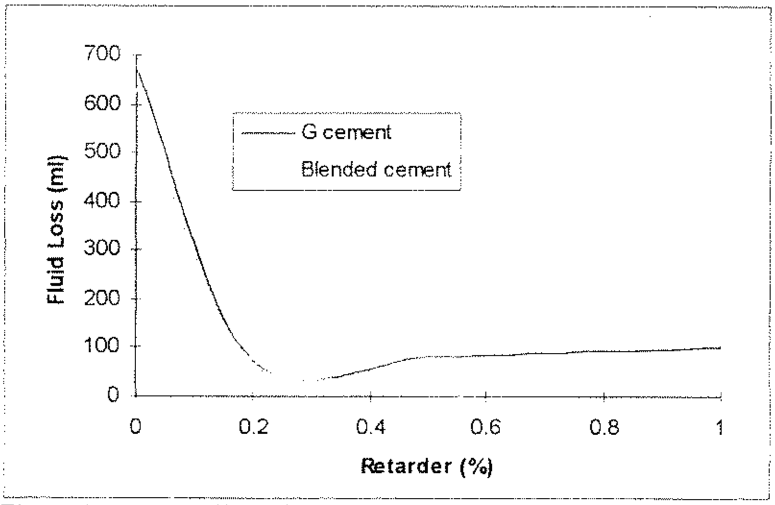

Figure 5. Effect of Retarder to the Fluid Loss (with 2% Fluid Loss Agent)

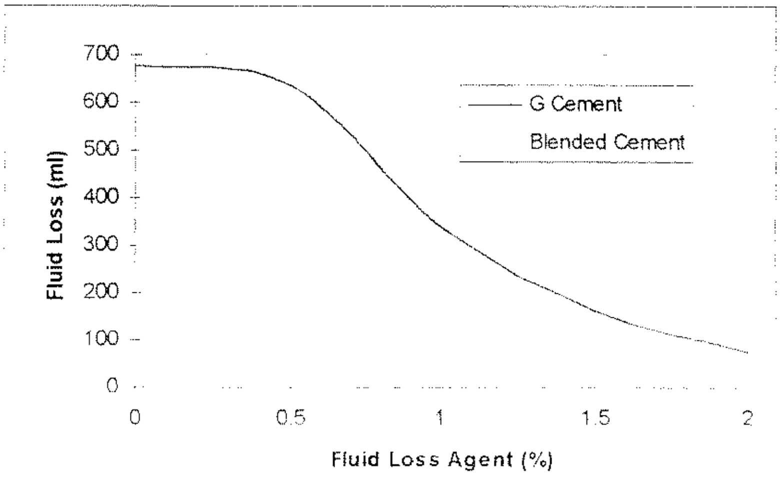

Fig. 6. Effect of Fluid Loss Agent to the Fluid Loss Volume (with 0.2% retarder)

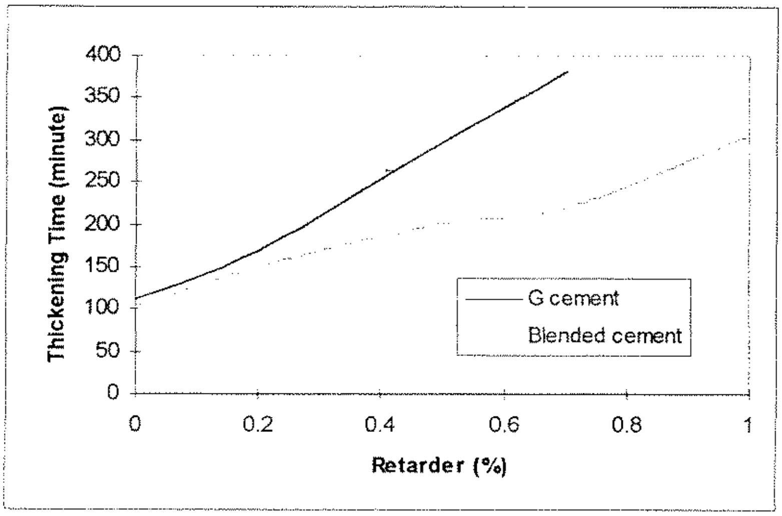

Figure 7. Effect of Retarder to the Thickening Time

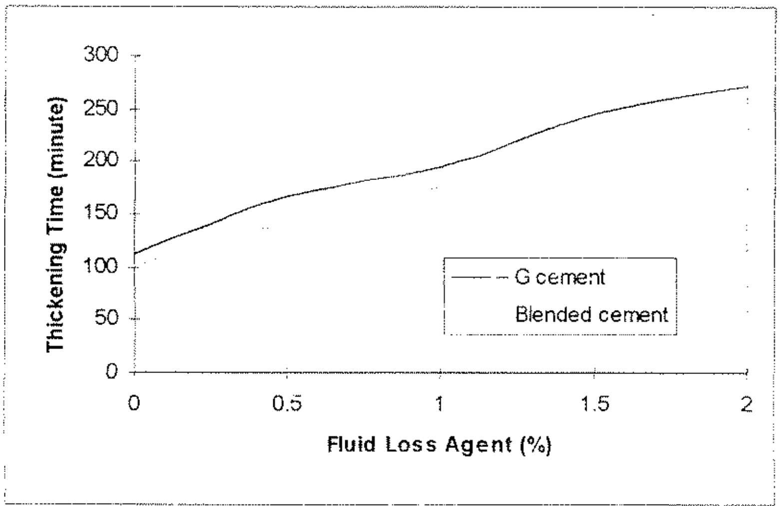

Figure 8. Effect of Fluid Loss Agent to the Thickening Time

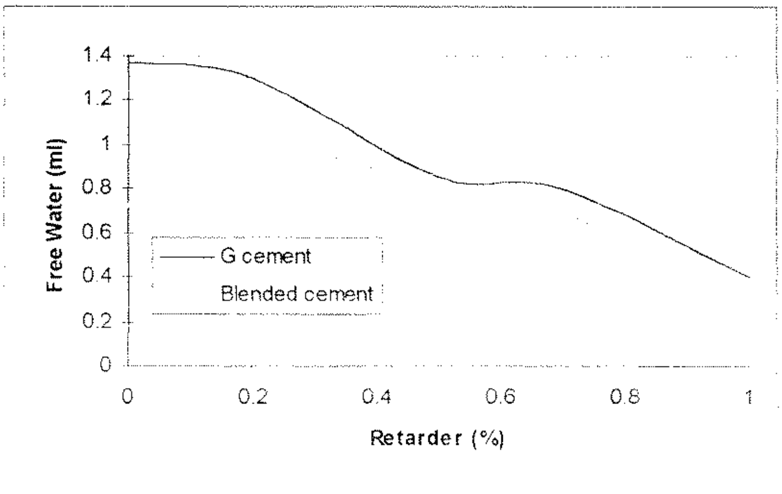

Figure 9. Effect of Retarder to the Free Water Content

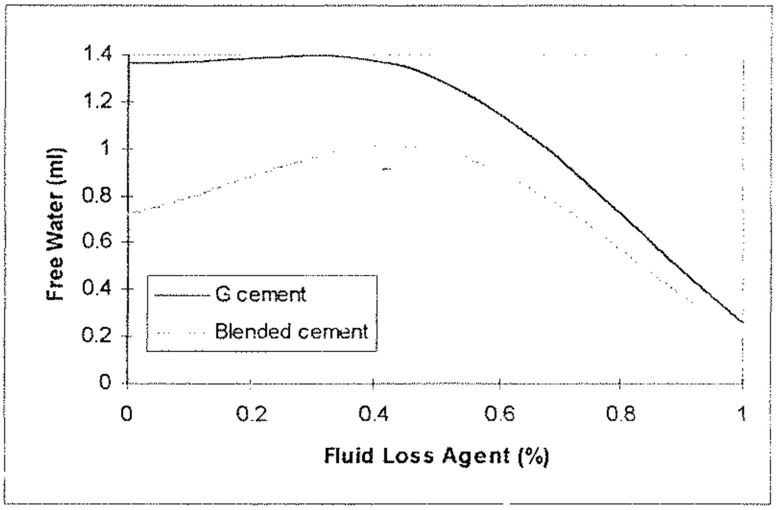

Figure 10. Effect of Fluid Loss Agent to the Free Water Content

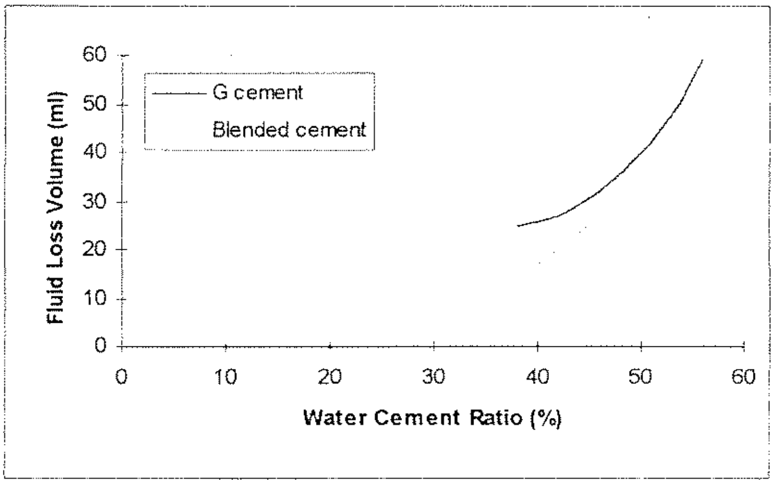

Figure 11. Effect of Water-Cement Ratio the Fluid Loss Volume

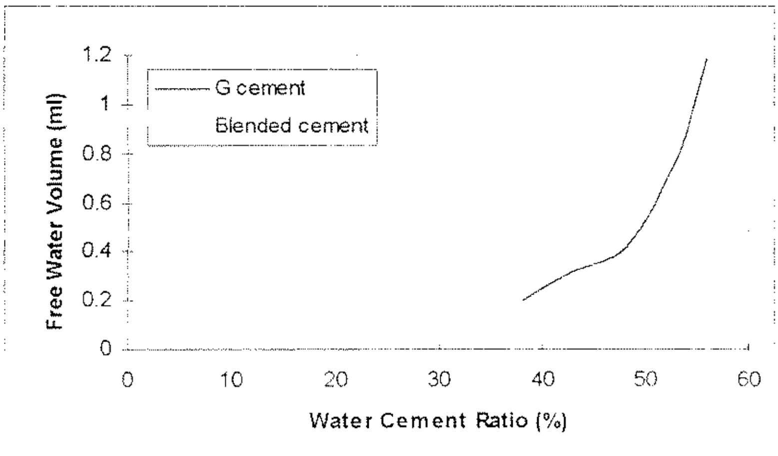

Figure 12. Effect of Water-Cement Ratio to the Free Water Volume