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Full Length Research Paper

Optimization of plug utilized in lost circulation treatment while drilling

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The major problem of oil wells drilling is circulation lost that can occur near weak formations and before well cementing. Conventional methods such as lost circulation material pills, cement plugs and dual injection were used to combat different types of massive mud loss in spite of their small success rate and high cost and risk. A different circulation treatment has been introduced to optimize plugging of loss zones by minimizing cost and time. It consists of combining InstanSeal (seal formation instantly) and cement to improve the mechanical performance of the system. InstanSeal-cement plugging fluid is a loose invert emulsion (water-in-oil) that gels rapidly in normal drilling operations after passing through the drill bit nozzles resulting in a rigid direct emulsion (oil - in- water) which will be squeezed and penetrated into weak formations to seal it. It is the only gelling system that uses mechanical means as a trigger mechanism. The present work aims to optimize the emulsion mechanism, the composition effect and the InstanSeal-cement as follows: (i) Introduce the InstanSeal-cement as an approach to cure massive losses where conventional methods fail. (ii) Analyze the evolution of InstanSeal-cement fluid by changing each product concentration. (iii) Find the proper emulsion of each kind of losses. (iv) Optimize the system according to the equipment taking into account the mixing energy. (v) Find the most effective formulation using mathematic models. (vi) The laboratory pre-checks will be taken as helping data to minimize the failure risk. After the success results obtained from the yard test, the InstanSeal-cement proved that it is competent to cure massive losses by improving the success rate (80%). This economic success can be matched by reducing risks, achieving excellent results and decreasing drilling time through a critical section.

Key words: InstanSeal, drilling fluid, circulation lost, optimization.

INTRODUCTION

Drilling fluids, such as mud, are fluids used to drill a hole through the earth crust. They circulate down the rotating drill pipe through the bit and up the annular space between the pipe and the formation or steel casing; to the surface (Henry et al., 1983).

In many parts of the world specific techniques and methods are being implemented to combat massive mud loss and save the well in spite of their cost, time consumption and risk (Tailleur, 1963). Instanced-cement is a ''patented circulation treatment'' which was developed as a solution to cure lost circulation problems while drilling when conventional methods fail. It is defined as a single fluid able to cure massive mud losses instantly by being pumped through the drill bit nozzles (www.connect.slb.com. *Mark of Schlumberger, 1999).

This shear-sensitive plugging fluid was designed to gel rapidly after passing through the bottom hole assembly in normal operations, thus forming a solid mass. It is a gelling system which uses mechanical means as a trigger mechanism to develop its initial compressive strength but not to consolidate the formation. Before developing some gel strength, the plugging fluid maintains the rheology of the drilling fluid allowing its penetration into the loss zone

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Table 1. Some test samples.

Test number	1	2	3	4	5	6
Oil-water ratio (%)	30	25	20	30	25	20
Gas oil (ml)	120	100	80	120	100	80
Emulsifier (ml)	5	5	5	8	8	8
Bentonite (g)	12.5	12.5	12.5	12.5	12.5	12.5
Cross linker (g)	4	4	4	4	4	4
Viscosifier (g)	7.5	7.5	7.5	7.5	7.5	7.5
Cement (g)	250	250	250	250	250	250
Water (ml)	280	300	320	280	300	320

where it actually stops and provides a permanent sealing.

STANSEAL-CEMENT REACTION MECHANISM

This plugging fluid is activated by mechanical means to give rigid gel that allows the lost circulation zone to be closed off quickly and continue drilling (David et al., 1999).

Definition

InstanSeal-cement is a single reactive fluid which is based upon what is termed a “ loose” invert emulsion that is (water - in - oil) or “ shear-sensitive’’ invert emulsion. This is due of the degree of instability towards high shear forces. It consists of: oil emulsifier, bentonite, cross-linker, viscosifier, class G cement and water.

Functioning principal

The shear activated gel consists of two phases -water and oil- emulsion. The internal phase of the loose plugging fluid (water) consists of a high polymer concentration (water soluble polymer) and the continuous phase (oil) contains a cross linker and cement. Upon exposing the fluid to high shear forces (pressure drop across small orifice) the loose invert emulsion undergoes very rapid deformation and flips to more stable direct emulsion (oil in water). Enough energy must be imparted to the system to invert the emulsion. This is accomplished by shearing the fluid with about 500 psi differential pressure at the drill bit.

Reaction mechanism

To provoke and initiate the emulsion inversion (the mechanical reaction between the reactive species) a minimum shear threshold must be achieved. When the loose invert emulsion is subjected to high shear forces, the emulsion flips and results in a rupture that releases both the encapsulated cross linker and the cement from the oil phase to the new water continuous phase, allowing the cross linker to contact the polymer that triggers the gel, forms a solid mass and initiates the cross-linking reaction almost instantaneously. The final product is a rigid, robust, very hard, but plastic gel created in few minutes after passage through the bit.

The loose emulsion is maintained by a low concentration of an emulsifier. The surface of the cross linker is oil wet and remains in the oil phase. The high shear triggers a rupture in the interfacial membrane of the emulsion by making the large water droplets ruptured to give an emulsion containing more stable numerous and smaller diameter oil droplets. The interfacial tension between the two phases is maintained by the emulsifier (surfactant) that reduces the surface tension between the water droplets and the oil (Parvazinia and Nassehi, 2006).

Chemistry of cross linked gel

The viscosifier is a water soluble polymer (polysaccharide) which has hydroxyl groups along its chain. In a specific pH region an oligomerisation is occurred by the creation of cross linked bond between hydroxyl groups and metallic polyvalent ions or other organic molecules.

The transfer of the cross linker into the high concentration polymer slurry is rapid. This is why this system (gelling time) is temperature independent http://www.slb.com/services/cementing/lost_circulation/instant_seal.aspx. The instability of the loose emulsion is exploited to create the new technology.

EXPERIMENTAL

Check ratio and interpretation

Table 1 discusses the test sample and Table 2 discusses the manipulation observation. However, the other tests have been performed in a similar way.

Table 2. Manipulation observation.

Test number	Observation
1	Good mixability and very viscous fluid, pH: 11.62, Gelling time: 7 s
2	Good mixability and less viscous fluid, pH: 11.65, Gelling time: 6 s
3	Difficult mixability, pH: 11.66, Gelling time: 5 s
4	Good mix ability, pH: 11.37, Gelling time: 65 min
5	Good mixability, pH: 11.67, Gelling time: 55 min
6	Acceptable mixability, pH: 11.69, Gelling time: 55 min.

Table 3. OWR effect.

OWR	pH	Gelling time (min)	Gel strength (psi)	Plastic viscosity (cp)
20	11.69	55	5.829	42
25	11.67	55	6.119	12
30	11.37	65	6.003	03

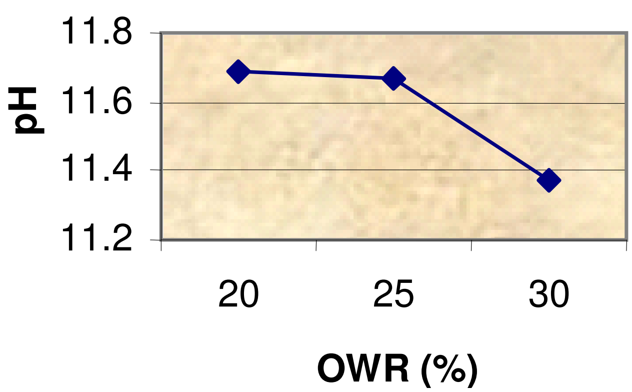

Figure 1. OWR effect on pH.

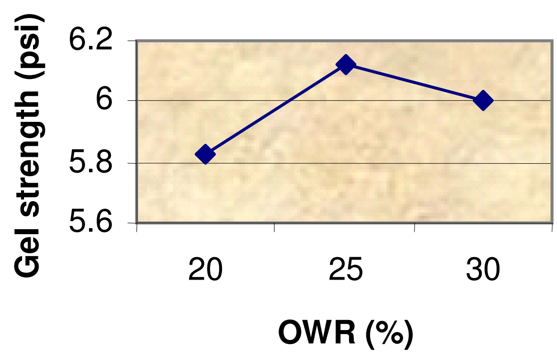

Figure 3. OWR effect on gel strength.

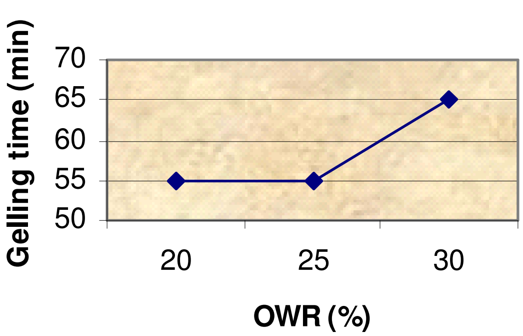

Figure 2. OWR effect on gelling time.

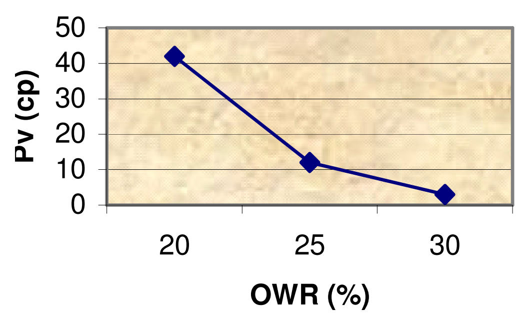

Figure 4. OWR effect on plastic viscosity.

RESULTS AND DISCUSSION

OWR (oil-water-ratio) effect

Table 3 and Figures 1 – 4 discuss the OWR effect. The impact of the oil-water-ratio on the other parameters is less important except on the viscosity.

Emulsifier effect

Table 4 and Figures 5 to 7 discusses the emulsifier effect.

Table 4. Emusifier effect.

Emulsifier (ml)	Plastic viscosity (cp)	Gelling time (min)	Gel strength (psi)	
			4 h	24 h
1.5	48.00	1.50	5.539	6.011
2.0	37.50	1.66	7.012	8.528
2.5	33.02	2.00	7.111	8.873
3.0	30.02	2.16	8.211	8.886
3.5	21.00	2.50	9.302	9.418
4.0	18.00	3.00	9.302	10.711
4.5	15.01	4.00	9.302	11.153
5.0	15.00	4.50	9.302	11.850
5.5	15.00	12.00	9.201	11.502
6.0	15.00	14.00	0	11.414
6.5	15.00	25.00	0	11.072
7.0	15.00	26.00	0	10.794
7.5	15.00	28.00	0	10.223
8.0	14.80	180.00	0	10.105

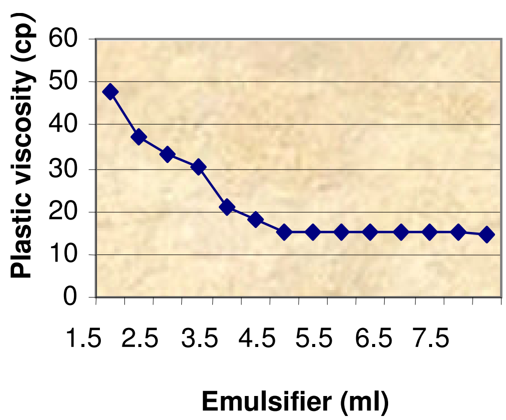

Figure 5. Emulsifier effect on rheology.

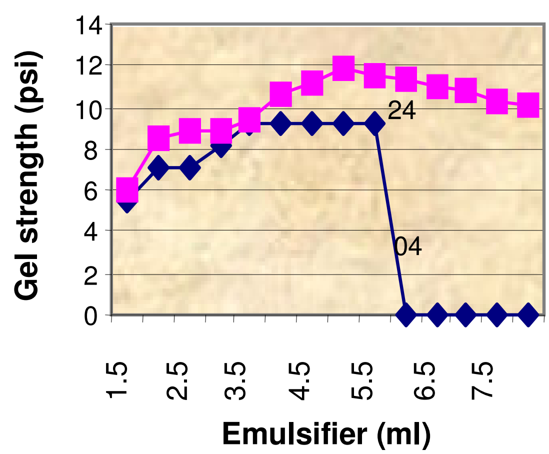

Figure 7. Emulsifier effect on gel strength.

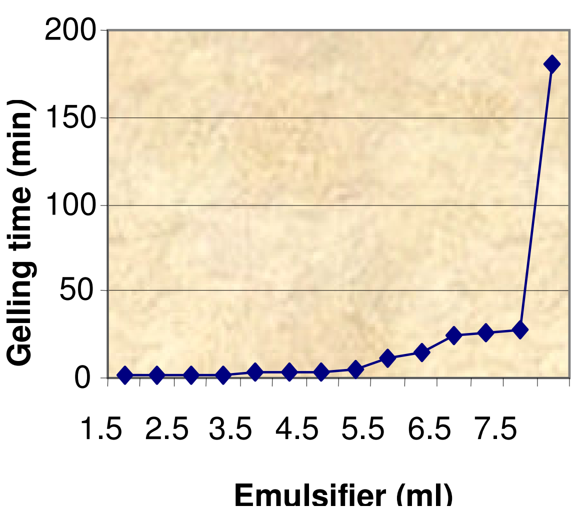

Figure 6. Emulsifier effect on gelling time.

Formulations with emulsifier = 5 ml

5 ml as emulsifier concentration is enough to facilitate the mixing and create the emulsion. However; the gelling time obtained with this concentration is not adequate to cure losses. It is very short and it can prevent the InstanSeal-cement from the penetration into the loss zone to seal it. Therefore, to continue the study a high concentration of emulsifier is added with maintaining the same reference design.

Formulations with emulsifier = 8 ml

If the OWR is low the mix ability can not be easy because the water volume is high. High OWR leads to improve the gel strength which means that the InstanSeal-cement is hard. For a high OWR, the obtained pH value is not high in comparison to that for low OWR. This means that the cross linker and cement are well protected in the oil phase (cross linking reaction is slow). The loose emulsion is more stable.

The slow release of the cement and the cross linker give a delayed gelling time. This is observed where OWR is high. High rheology property indicates the best transfer of the cement and the cross linker. This can be observed in the formulation where OWR is low. A reduced gelling time and an acceptable plastic viscosity with a better gel strength were observed with OWR: 25.0% and OWR: 75%. Therefore this ratio is chosen as the base ratio.

Observations while checking

For OWR 25% and OWR 75% the InstanSeal-cement cubic samples treated for 24 h in the curing chamber are deformable by applying a high finger pressure. This means that this formulation can be used as a plug to cure losses but it stays soft after 24 h from injecting.

Interpretation

For the formulation without emulsifier it was not observed any emulsion (bad mixing). But a high emulsifier concentration leads to an easier mixing. Increasing the emulsifier concentration delays the gelling time owing to the good curvature of this surfactant around the water droplets by minimizing the transfer of cross linker and cement from the oil phase to the water phase. This slow diffusion is the reason for getting a very long gelling time. The minimal transfer gives reduced values of rheology and pH. An exceeded concentration of emulsifier may prevent the InstanSeal-cement from setting (as it is shown in the last test where emulsifier = 8 ml which gives more than three hours as a gelling time and makes the formulation useless.

The formulations leading to a short gelling time should not be prepared to cure losses (InstanSeal-cement can not penetrate into the loss zone) whereas a long one can cure minor losses.

The high concentration of emulsifier reduces the gel strength. It is also observed that the evolution of the gel strength between 4 and 24 h is not well developed. Therefore the operator can continue drilling before 24 h from pumping. This proves that the emulsifier has a slight effect on the gel strength.

Emulsifier has a strong effect on the gelling time of the InstanSeal-cement

Bentonite effect

Table 5 and Figures 8 and 9 discuss the effect of bentonite.

Table 5. Bentonite effect.

Bentonite (g)	Gelling time (min)	Gel Strength (psi) 4 h	Gel Strength (psi) 24 h
0	125	10.994	11.082
5	6	11.512	11.862
10	5	11.563	12.636
11.5	5	12.056	12.697
12	4.5	12.205	12.679
12.5	4.5	12.218	12.884
13	3.5	12.220	13.039
15	3	12.242	13.114
20	3	0	15.328
25	3	0	0

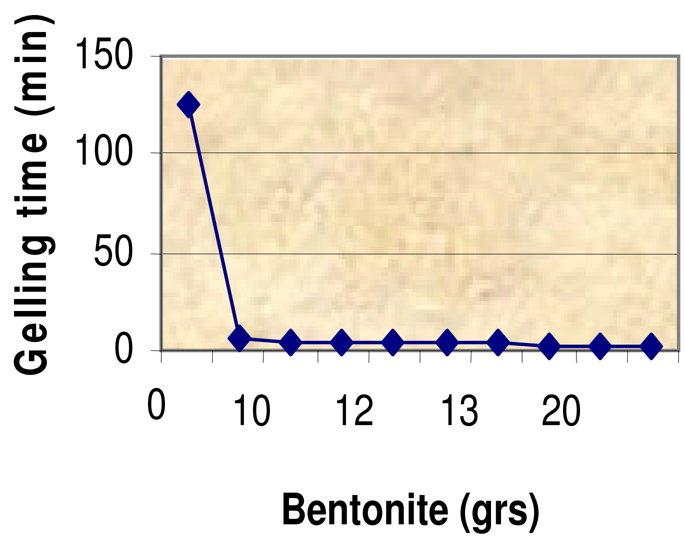

Figure 8. Bentonite effect on gelling time.

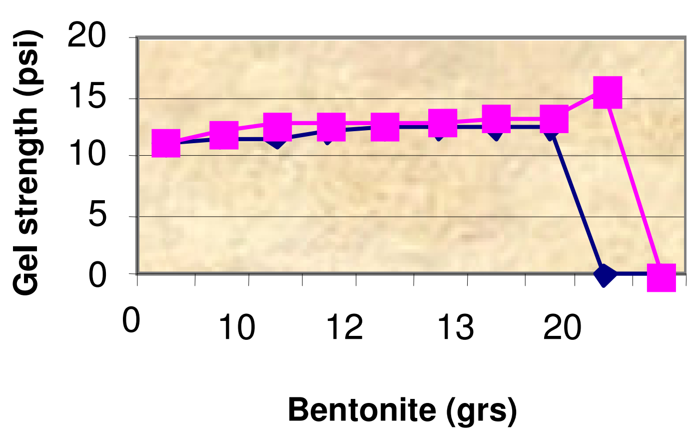

Figure 9. Bentonite effect on gel strength.

Table 6. Cross linker effect.

Cross linker (g)	Gelling time (min)	Gel Strength (psi) 4 h	24 h
0	120	0	11.011
2	20	13.353	14.516
2.5	12	14.209	14.827
3	8	14.209	14.843
3.5	6	14.210	14.853
4	4.5	14.312	14.950
4.5	3	14.820	15.054
5	2	15.101	15.679
5.5	1.5	15.516	16.037
6	1.33	15.269	17.329

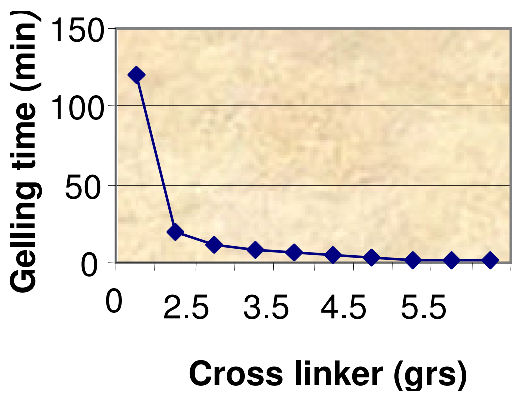

Figure 10. Cross linker effect on gelling time.

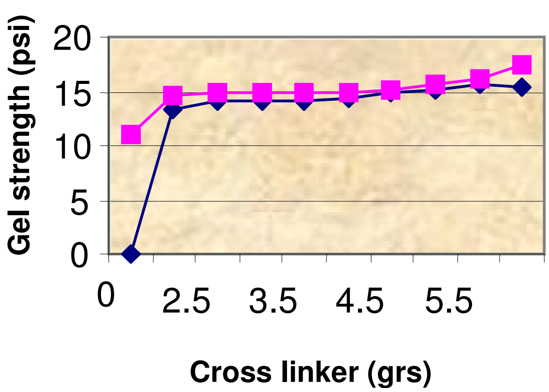

Figure 11. Cross linker effect on gel strength.

Observations while checking and results interpretation

Preparing formulation without bentonite gives an inconsistent emulsion. Thus the solids were sedimented at the bottom of the container and a very high quantity of water was not absorbed. This proves that the bentonite is the water absorption responsible. The bentonite is an accelerator (gelling time is reduced by adding more bentonite). Thus the presence of solid particles provides another shear forces to the system. In the range of 15 - 25 g the bentonite could not reduce the gelling time less than 3 min. This means that it has a slight impact on the gelling time of the InstanSeal-cement. According to the charts built, it is noted that the bentonite has a slight impact on the gel strength since its increase results in a slight increase of the gel strength.

The impact of the bentonite on the InstanSeal-cement behavior is too slight

Cross linker effect

Table 6 and Figures 10 and 11 discuss the cross linker effect.

Observations while checking and interpretation

Preparing the InstanSeal-cement without cross linker gives a much delayed gelling time (several days). This means that the cross linking reaction (which results in the gelling) did not occur. The buffer resists the change in its hydrogen ion concentration; therefore the pH is maintained in the following range [1.45 -1.58].

The cross linker is a solid that gives additional shear energy to the system and reduces the gelling time. Adding more cross linker allows to more transfer of cross linker and cement. But using a very high amount may provoke an early gelling that prevents the InstanSeal-cement from the penetration into the loss zone.

Fast release of cross linker results in a reduced gelling time and a high gel strength

Viscosifier effect

Table 7 and Figures 12 -14 discuss the viscosifier effect.

Observations while checking and interpretation

Preparing the InstanSeal-cement without viscosifier gives a fluid with solids at the bottom of the container and a partial phase separation. It was also observed that this formulation did not accept any shearing (stays loose emulsion). The presence of the viscosifier that is cross linked after shearing induces of the cross linking reaction which means improving the gel strength. The gelling time is reduced and the viscosity increased by adding more viscosifier.

Table 7. Viscosifier effect.

Viscosifier (ml)	Plastic viscosity (cp)	Gelling time (min)	Gel Strength (psi)	
			4 h	24 h
3	17.087	30	4.666	5.628
6	18.012	7	9.9972	10.139
6.5	18.012	5.5	13.377	13.884
7	21.014	4.5	13.651	14.276
7.5	24.017	4.5	13.879	14.386
8	27.019	3.5	14.545	15.997
9	36.025	3.5	15.029	17.304
10	40.001	3	15.279	18.464

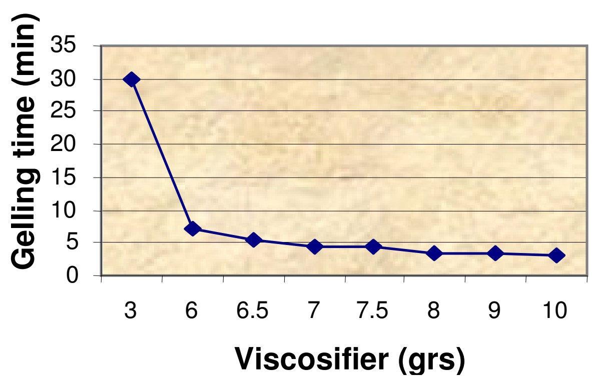

Figure 12. Viscosifier effect on gelling time.

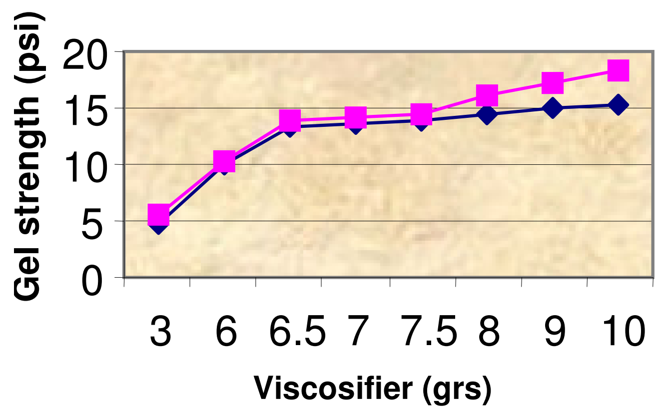

Figure 14. Viscosifier effect on gel strength.

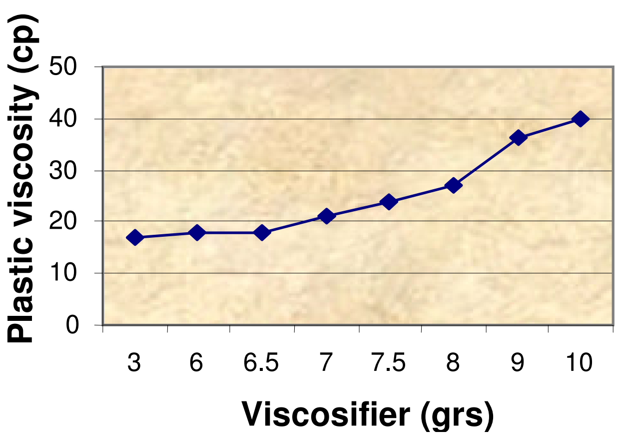

Figure 13. Viscosifier effect on rheology.

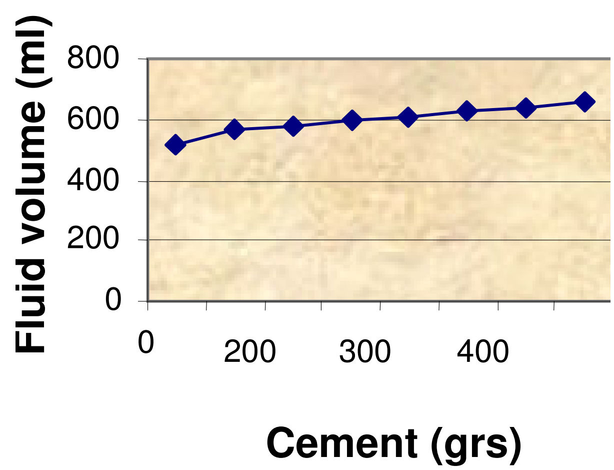

Figure 15. Cement effect on fluid volume.

An increase of the viscosifier content has a little effect on the gelling time but improves the gel strength

Cement effect

Table 8 and Figures 15 -20 discuss the cement effect.

Observations while checking and interpretation

Preparing the InstanSeal without cement gives a very soft touch to the sample therefore introducing the cement to the classic InstanSeal-cement leads to improved gel

Table 8. Cement effect.

Cement (g)	Fluid volume (ml)	Fluid density	Shear stress (lbf/100 ft)	pH	Gelling time (min)	Gel	Strength (psi)
0	516.64	0.97	142.37	9.41	100	0	0
150	563.81	1.17	146.14	10.70	20	0	11.584
200	579.53	1.22	157.37	11.42	17	11.703	13.731
250	595.26	1.25	174.37	11.48	4.5	13.650	14.380
300	610.98	1.33	182.38	11.85	1.5	14.021	16.031
350	626.70	1.35	188.04	12.02	0.2	14.304	16.873
400	642.43	1.42	194.04	12.07	0	14.537	17.996
450	658.15	1.43	194.38	12.08	0	15.203	18.838

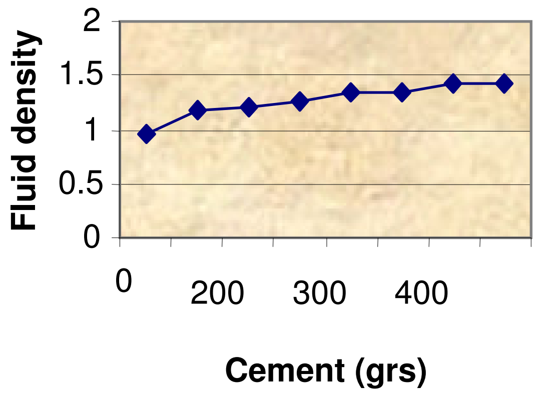

Figure 16. Cement effect on fluid density.

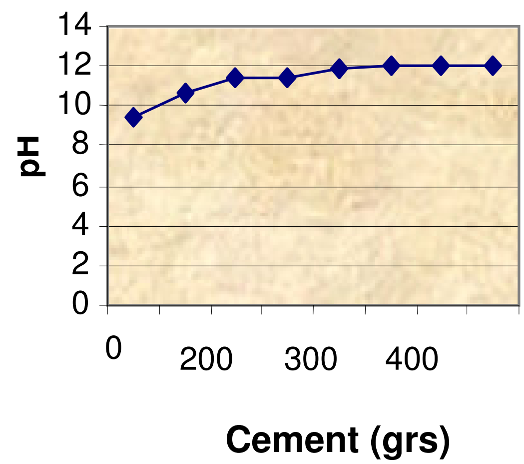

Figure 18. Cement effect on pH.

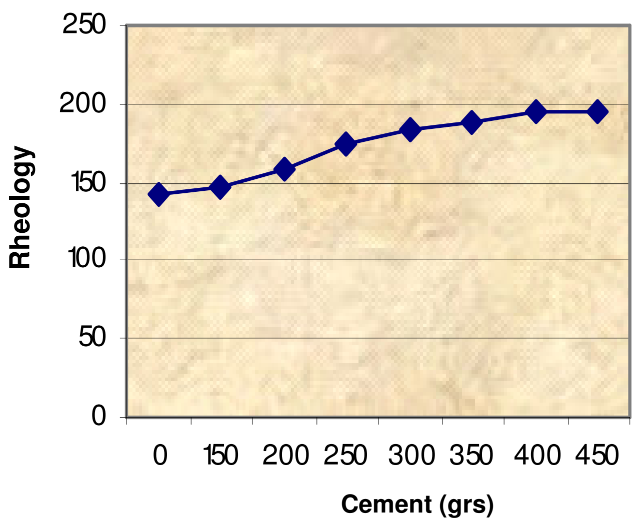

Figure 17. Cement effect on rheology.

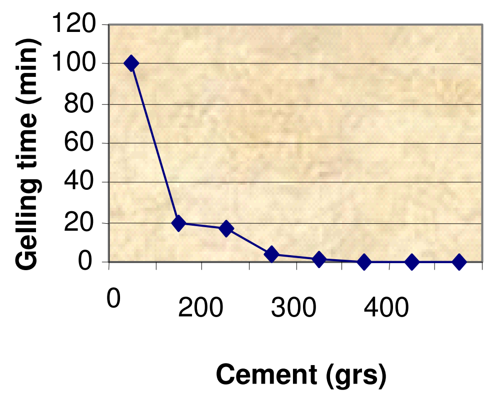

Figure 19. Cement effect on gelling time.

strength. Using a very high amount of cement (more [redacted]an 400 g) results in a difficult mixing and shearing. A [redacted]gh amount of cement reduces the gelling time becaus[redacted]he cement hydration contributes to the premature ge[redacted]ng through the release of divalent calcium ions. It leads also to high rheological properties (TY) that necessitates applying an initial pressure to facilitate the plugging fluid movement while pumping. Increasing the cement content leads to the increase of the gel strength and pH value (more than 12). This indicates that the reaction starts at

Table 9. Barite effect.

Barite (g)	Density	pH	Gelling time (min)	Gel	Strength (psi)
0	1.27	11.68	5	13.120	14.702
100	1.36	11.61	5	13.567	14.958
150	1.41	11.60	5	14.822	15.321
200	1.46	11.58	5	15.321	16.442
250	1.54	11.52	2	15.802	16.824
300	1.56	11.47	1.5	16.049	17.210
350	1.60	11.41	1	16.520	18.401
400	1.62	11.37	0.75	17.201	19.450

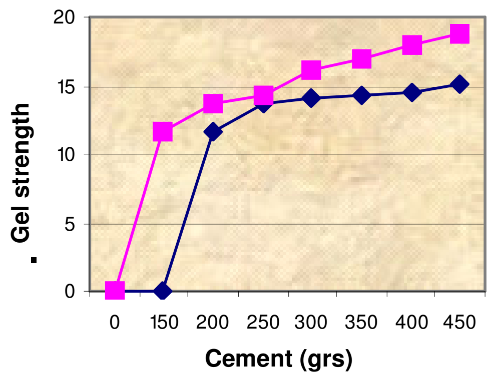

Figure 20. Cement effect on gel strength.

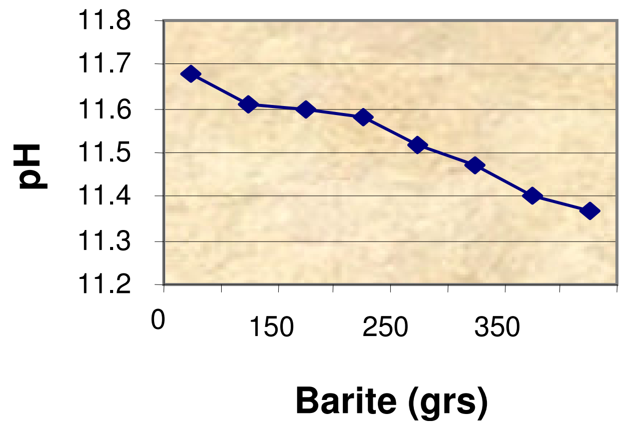

Figure 22. Barite effect on pH.

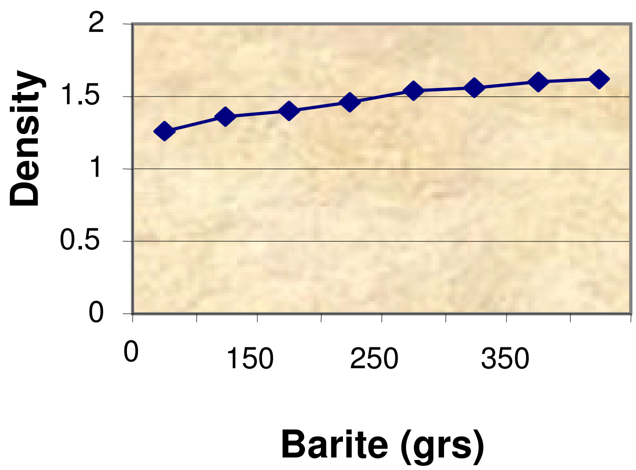

Figure 21. Barite effect on density.

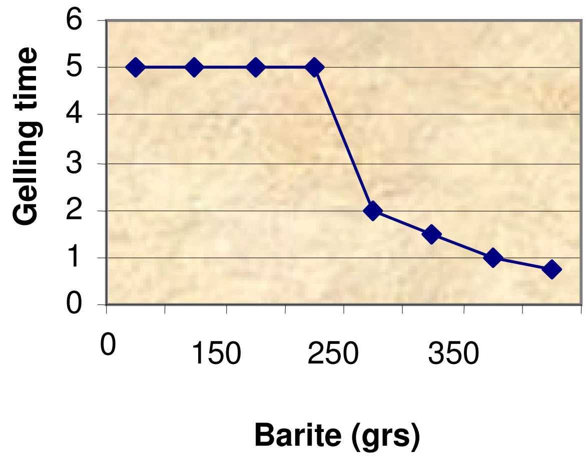

Figure 23. Barite effect on gelling time.

the surface (before shearing) because the cement hydration provides a second source of cross linker. That is why the cement should be added just before the job. Adding cement increases the InstanSeal-cement volume. This must be taken into consideration because the job application is limited by the equipment.

The cement leads to the better final mechanical properties and gains the compressive strength

Barite effect

Table 9 and Figures 21 -24 discuss the barite effect.

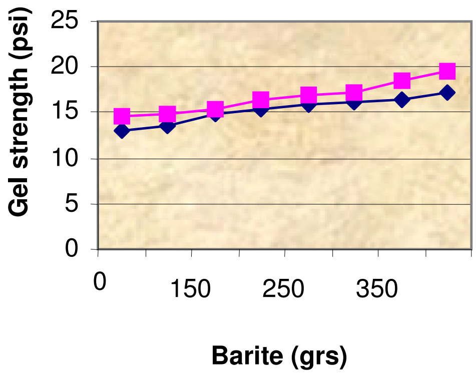

Figure 24. Barite effect on gel strength.

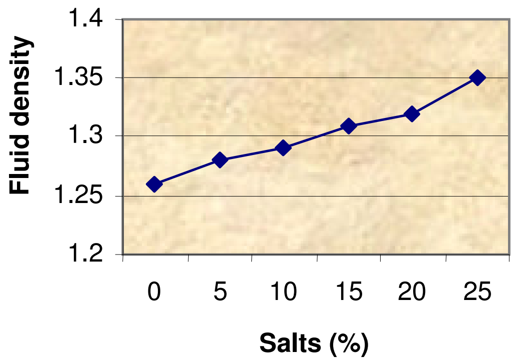

Figure 25. Salts effect on fluid density.

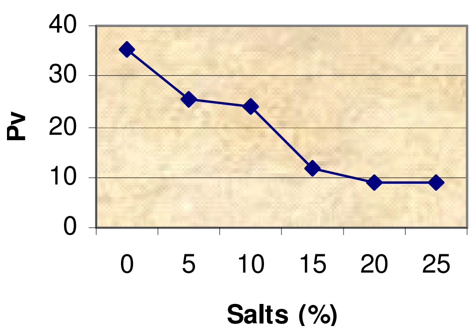

Figure 26. Salts effect on rheology.

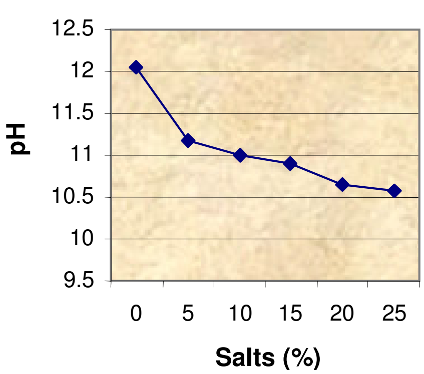

Figure 27. Salts effect on pH.

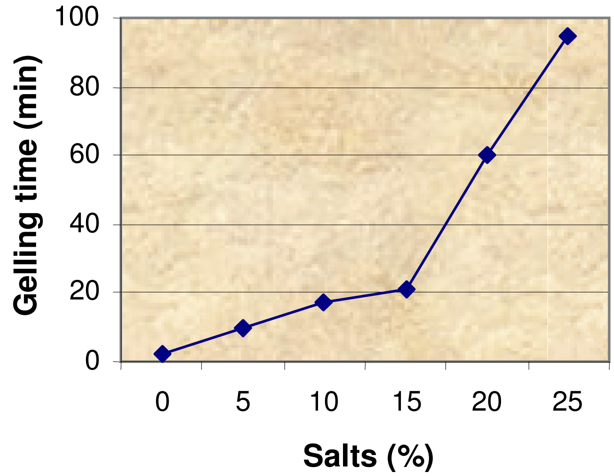

Figure 28. Salts effect on gelling time.

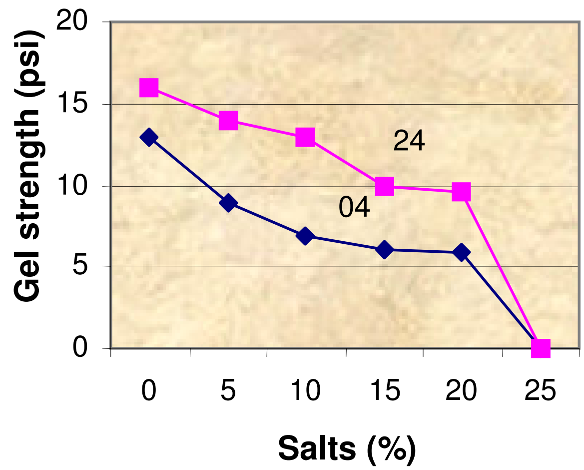

Figure 29. Salts effect on gel strength.

Observations while checking and interpretation

Adding weighting agents to the InstanSeal-cement leads to higher rheological properties and improves the gel strength. This weighting agent (barite) can accelerate the gelling time because the solid particles provide additional shear energy to the system and slightly impair the release of the cross linker and cement. This is why the pH value is reduced while increasing the weighting agent amount. Adding more barite gives a high value of density that reduces the contamination between the InstanSeal-cement and the well bore drilling fluid. The barite improves the stability of the gel.

Salts effect

Figures 25 -29 and Table 10 discuss the salts effect.

Table 10. Salt effect.

Salt (%)	Fluid density	Plastic viscosity (cp)	pH	Gelling time (min)	Gel	Strength (psi)
0	1.26	35.385	12.05	2	12.891	16.031
5	1.28	25.517	11.17	10	8.983	13.962
10	1.29	24.017	11.01	17	6.821	12.863
15	1.31	12.012	10.91	21	6.033	9.905
20	1.32	9.006	10.64	60	5.951	9.565
25	1.35	9.011	10.57	95	0	0

Observations while checking and interpretation

The salts increase the viscosity of the water. High amount of salt added to the water used to prepare the InstanSeal-cement can impair the cross linking reaction. This gives a reduced pH value, a delayed gelling time and weak gel strength.

Conclusions

(i) The resulting gel is robust in the initial phase and in the following days as the cement gains the compressive strength.
(ii) The cross linker must be released at a delayed rate to generate a suitable gelling time.
(iii) The gelling time can be increased or decreased by making the emulsion more or less shear sensitive.
(iv) The gelling time depends upon pressure and emulsifier concentration.
(v) The gelling time should be sufficient for fluids to enter the formation.
(vi) The InstanSeal cement requires follow-up with trying to mix with other additives to improve its feature and application range.
(vii) The salt is detrimental to the gel strength.

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