The Effect of Mixing Energy and Shear Rate on the Thickening Time of Cement Slurry

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Abstract

Achieving optimum cement slurry design involves being able to simulate actual field experience in the laboratory. This work is on how mixing energy and shear rate affect the thickening time of cement slurry.

Using conventional pressurized consistometer, fitted with a variable speed motor, a comparative thickening time test was obtained. This device allows for simulation of shear rate, temperature and pressure found in the well bore during pumping. The API procedure was used to evaluate the mixing energy applied to the slurry.

Results obtained show that for mixing energy, the principal thing is deflocculation. Once the slurry is deflocculated, then no other effect of mixing energy is felt on the thickening time and it is not a function of the geometry of wellbore. Results also show that the temperature profile and geometry of the well from surface to bottom is an important consideration in modeling the influence of shear on how long the cement slurry will remain pumpable. Modeling along this line will lead to optimum slurry quality and design.

Keywords

Cement Slurry; Mixing Energy; Shear Rate; Thickening Time (TT).

Introduction

Cementation is important in the petroleum industry. Its uses range basically from zonal isolation and protecting and supporting casing (main objective) to abandoning a section of the wellbore. Cement slurry is formed by mixing powdered cement with water. This is a hydration process. The particles of cement consist of agglomerates/aggregates held together by different inter-particles forces (van der Waals attractive force).

The mixing process involves:

i. Mixing (wetting)

ii. Deflocculating of agglomerate and aggregates

iii. Stabilization of the resulting suspension (paste)

Wetting requires replacing the air between each particle by water. To do this we must first deflocculate (breakdown of cement agglomerates and aggregates.) This is achieved by mixing the mixture at high speed so as to achieve a proper mixture forming the slurry. Mixing conditions are known to affect the consistency of cement slurry [1].

Cement slurry is placed by pumping to desired location in the well using hydraulic displacement mechanism. After pumping, the slurry becomes set (hardened), giving favorable strength. A good advantage of cement slurry is that it is pumpable and hardens readily even in under-water environment.

The drilling engineer must meet certain requirements for a good job to be achieved. This requirement is in line with achieving the best cement composition and the best placement technique.

Requirement for a good cement job include:

1. Composition and placement technique must be chosen so that the cement always achieves an adequate strength soon after placement in desired location.
2. Cement must remain pumpable long enough to allow placement to desired location.
3. Design must be such that, the length and density of the unset column result in sufficient pressure to control the movement of pore fluid while not damaging or fracturing the formation, etc.

In meeting the above requirements, certain tests have to be carried out to determine if a given cement composition will be suitable for a given well condition. Some parameters play important role in achieving this goal. Some of these parameters are thickening time, rheology, fluid loss, and setting time [2].

From the foregoing, a lot of requirements have to be met in order to achieve a good cement job. An important aspect is that the cement slurry must remain pumpable long enough to allow placement to desired location. To achieve this, we consider the consistency of the slurry. By this, we are looking at the thickening time of the slurry. The thickening time is the amount of time that it takes the cement slurry to remain pump-able under downhole condition. The apparatus used to measure the thickening time is called the consistometer.

Two important factors that affect thickening time are:

1. Shear rate (velocity gradient)
2. Mixing energy.

The definitions of these factors are as follows:

Shear Rate

A fluid traveling between two plates will exhibit a velocity gradient. This velocity gradient is called shear rate.

$$\gamma = \frac{V}{L} \quad (\sec^{-1}) \tag{1}$$

For circular object,

$$\gamma = \frac{V}{r} = \omega \ (\sec^{-1}) \tag{2}$$

where: γ=shear rate, $\sec^{-1}$, L=distance between the two plates, cm, V = velocity of the fluid, cm/s, r = radius, cm.

Shear rate is influenced by the temperature ranges downhole.

Mixing Energy

As earlier mentioned, cement slurry is a mixture of cement, water and additives. The mixing process is exothermic and the energy required to do this is called Mixing energy. Mixing energy can be mathematically expressed as [3, 4]:

$$\frac{E}{m} = \frac{k\omega^{2t} t}{V} \tag{3}$$

where:

÷ *E*=Mixing energy *(kJ)*

÷ $k=6.1 \times 10^{-8} m^5/s$ (found experimentally)

÷ *t*=Mixing time *(s)*

÷ ω=Rotational speed *(radian/sec)*

÷ *m*=Mass of the slurry *(kg)*

÷ *V*=Volume of slurry in the slurry cup *(L)*

From the above, it is seen that mixing time and rotational speed are the two parameters that can affect the mixing energy of any given cement slurry.

Apparatus

Electronic balance:-This is used for weighing dry cement, water and additives used in preparing the slurry.

Electronic blender:-This is a mixing device used in preparing the slurry. It is a two-speed propeller type mixer. Normally 600 *ml* of slurry is prepared. The mixer is operated at 4000 *rpm* for 15 *sec* during which the dry cement is added to water. This is followed by 35 sec at 12000 *rpm.*

Pressurized Consistometer:-This apparatus, which is also called a thickening time tester, is used to measure the thickening time of the slurry under simulated temperatures and pressures. It measures the thickening time of the slurry in API consistency [5] unit designated by B_c.

Atmospheric Consistometer:-This is a consistometer that is designed to be used for low temperature cement system. But today, it is used for conditioning slurries before rheology and fluid loss tests.

Rotational Viscometer:-This is used to determine the viscometer of the slurry. Most times this is done after conditioning the slurry in the atmospheric consistometer.

Experimental Procedures

Preparation of slurry

According to API specification [6], the water and cement are measured using the electronic balance. The water is then poured into the mixing device. The blender is allowed to rotate for 15 *sec* at 4000 *rpm* during the period the cement is added to it. And then is allowed to mix for different duration of time at a rotational speed of 12000 *rpm*.

Thickening time test

This test is designed to determine how long the cement slurry will remain in a fluid state under simulated downhole condition without any shutdown periods. After preparing the slurry in the blender, it is poured into an API slurry cup. The volume of the API slurry cup is 600ml. The slurry cup is then placed inside the consistometer. The temperature and pressure are set on the machine and then the test is allowed to run. The consistometer used is a high pressure high temperature (HPHT) consistometer. The heating medium is an oily fluid. The time it takes to reach a consistency of 100*Bc* is regarded as the thickening time of the slurry. The shear rate-thickening time data are obtained by using a special consistometer with a variable speed stepping motor installed in it.

Rheology Measurement

The slurry was prepared in the same way as the slurry used for the thickening time experiment, applying the same mixing energy for each experiment. The slurry is then taken to the rotational viscometer where the viscosity is determined. The dial readings at different rotational speed were obtained giving the slurry behavior at surface condition. After this, the slurry is poured into a slurry cup designed for an atmospheric consistometer and placed inside the atmospheric consistometer. This helps to simulate downhole conditions. A heating fluid supplies the heat after conditioning for 20 *min*, at simulated downhole temperature of 52°*C (125.6°F).*

After conditioning, the slurry is now taken back to the viscometer to take the dial reading again. This gives rheological parameters at downhole condition.

Precautions

Some precautions taken to ensure a good result during the course of this work include:

1. The slurry must not be kept too long in order to prevent the slurry from caking.
2. Slurry cup must be washed after each experiment.
3. The bob and rotor of the viscometer must be washed in other to remove cement from its body.
4. Care must be taken in regulating the pressure in the consistometer.

Data Presentation and Analysis

The aim of the experiment is to investigate the effect of mixing energy and shear rate on the thickening time of cement slurry. In carrying out this experimental research, additives were not used.

Table-1 shows parameters used for the mixing energy and thickening time experiment:

Table 1**.** Parameters for the Experiment

Mass of cement	749g
Mass of water	392g
Initial pressure	1000psi
Final pressure	5160psi
Temperature	52^oC (125.6^oF)
Time to temperature / pressure	28 mins

Mixing energy calculation

Five experiments were carried out and reported in Table 2 below. The mathematical expression in equation (3) above was used in computing the mixing energy. The thickening time data for the different mixing energy are read directly from charts. These charts are presented in Figure 1–5.

Table 2. Showing mixing energy and Thickening Time at different rotational speed and time

Experiment	**Rotational Speed(rpm)**	**Time(Sec)**	**Mixing Energy(kJ/kg)**	**Total Mixing Energy(kj/kg)**	**Thickening Time(mins)**
1	4000	15	0.27	5.89	150
	12000	35	5.62		
2	4000	15	0.27	19.53	128
	12000	120	19.26		
3	4000	15	0.27	48.42	121
	12000	300	48.15		
4	4000	15	0.27	96.56	108
	12000	600	96.29		
5	4000	15	0.27	144.71	60
	12000	900	144.44		

Table-2 shows that as mixing time is increased, the mixing energy increases.

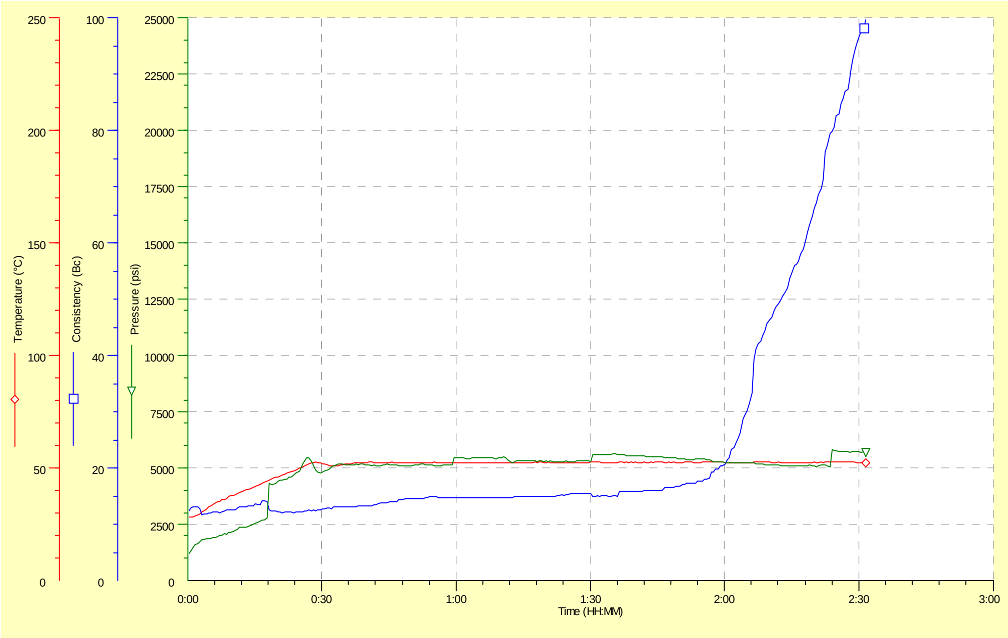

***Figure1**. Thickening time chart for experiment 1*

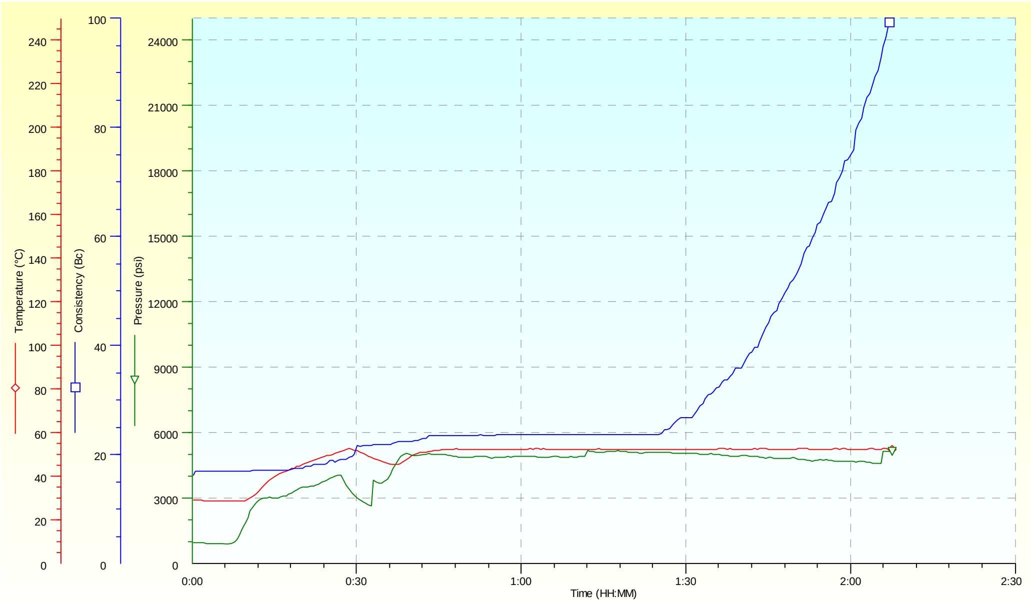

***Figure 2**. Thickening time chart for experiment 2*

Figure 3. *Thickening time chart for experiment 3*

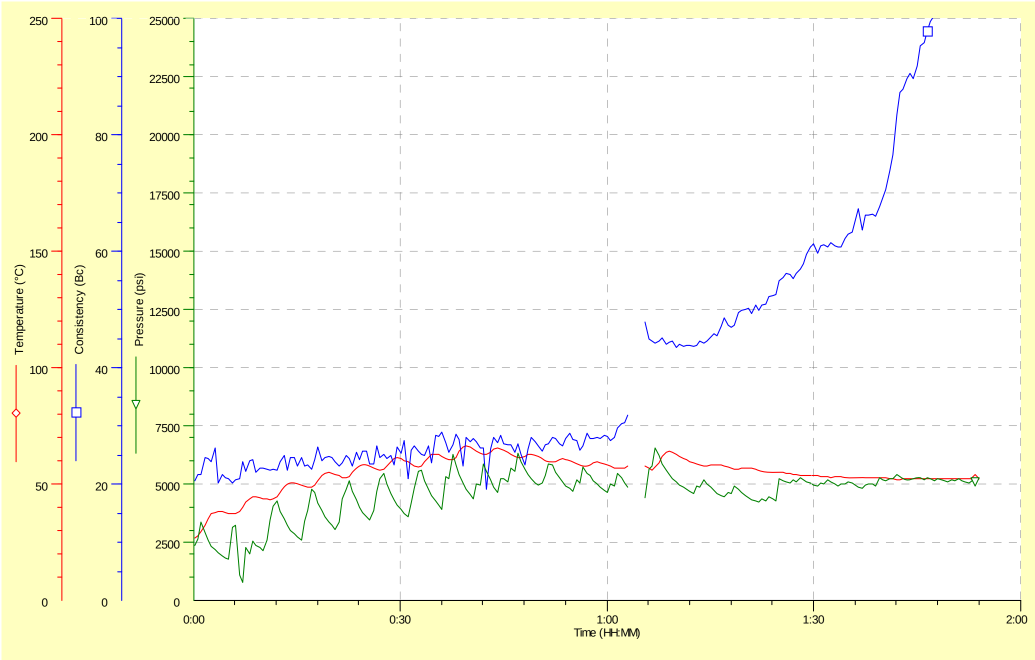

Figure 4*. Thickening time chart for experiment 4*

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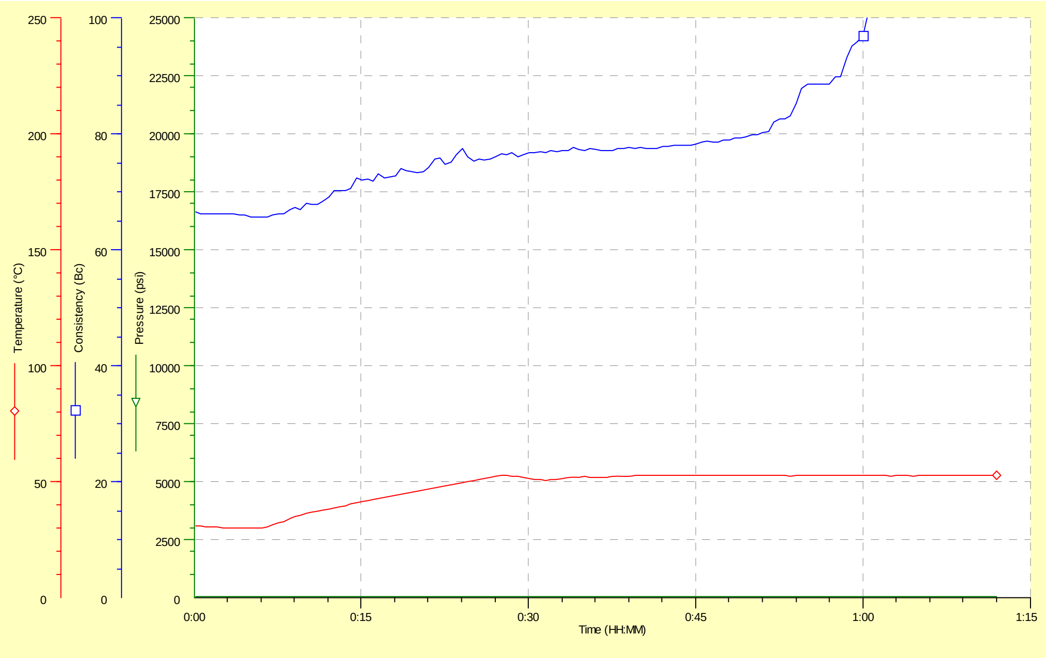

***Figure 5**. Thickening time chart for experiment 5*

Figure 6 is a plot of thickening time against mixing energy. From the graph, it is evident that as mixing energy increases, the thickening time reduces.

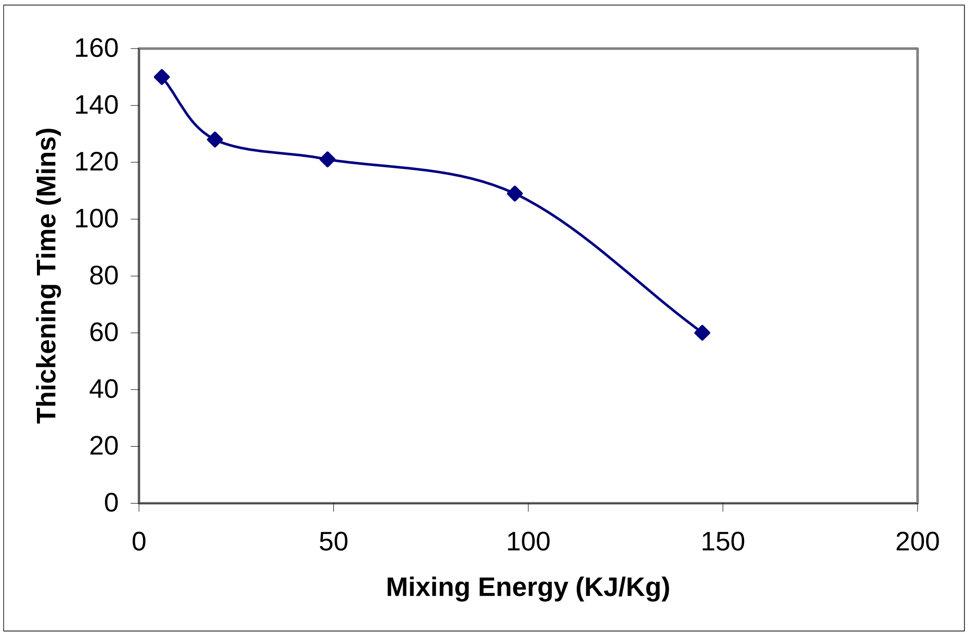

***Figure 6**. A plot of thickening time against mixing energy*

Shear rate estimation

Using class G cement and additives the shear rate history of the well was analyzed and the results are presented below. The shear rate was estimated at different temperature as we pump the slurry downhole. This is presented in the Table-3 and Figure 7.

Table 3. Showing shear rate and thickening time at different temperatures

Temperature (°F)	Shear Rate (rpm)	Thickening Time (hrs)
75	150	4
	18	2.5
	2	1.7
90	150	2.2
	18	1.45
	2	1.18
125	150	1.7
	75	1.6
	18	1.4
197	150	2.8
	18	5.5
308	150	3.25
	75	3.0
	18	2.25

Plotting a graph of shear rate versus thickening time at the different temperatures in the table above, we have:

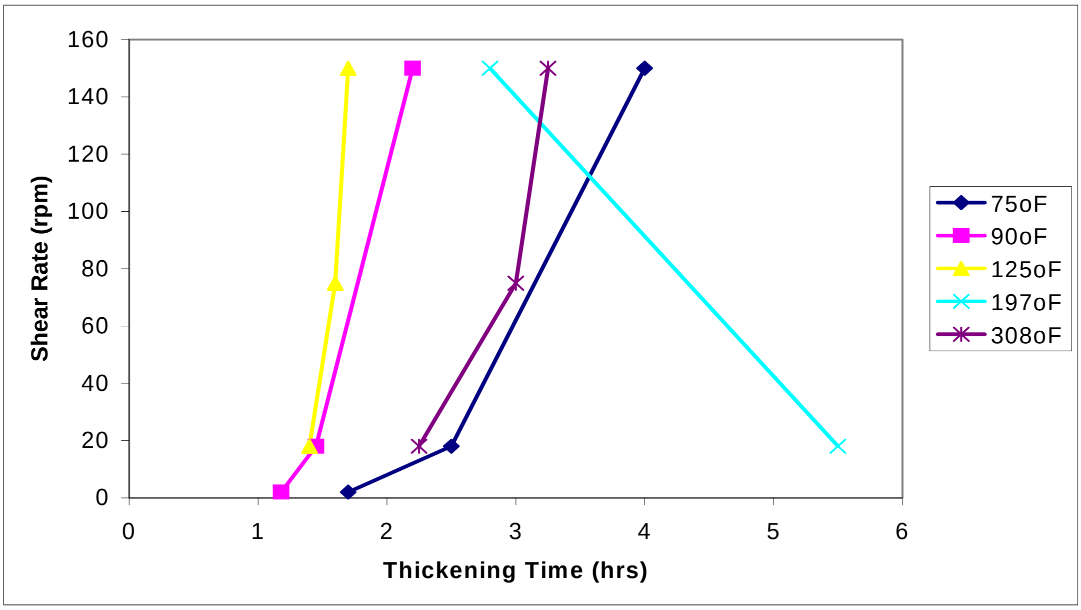

***Figure 7**. Shear rate (rpm) versus thickening time (hrs)*

From figure 7, it is seen that thickening time in actual field cases is a function of shear rate history and the temperatures experienced in the well from surface to downhole.

Conclusions

Based on the experiment carried out and research made on the effect of mixing energy and shear rate on thickening time of cement slurry, the following conclusions are reached:

1. As soon as hydration is initiated, the cement begins to set. This affects the mixing energy because while mixing, the cement is setting.
2. The critical step in mixing process is deflocculation.
3. As mixing energy increases, thickening time reduces.
4. If the slurry is deflocculated, any further alteration of the mixing energy will have little or no effect on thickening time.
5. Mixing time is a critical parameter in the mixing process.
6. Low mixing time reduces the yield of the slurry.
7. Long mixing time increases the yield of the slurry.
8. Proper application of mixing energy improves thickening time.
9. Shear rate as gotten from field experience is not represented in the thickening time experiment in the laboratory. This leads to long waiting-on-cement (WOC).
10. The temperature experienced downhole is important in shear rate-thickening time derivatives.

Nomenclature

Bc=Bearden unit

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