Expandable Resin for Countering Severe Loss of Circulation

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Abstract /

One of the main reasons why loss of circulation is difficult to remedy is the lack of knowledge about accurate fracture width and depth encountered while drilling, leading to an improper selection of suitable plugging materials that can adapt — in both volume and shape — to effectively plug a wide range of fractures with unknown dimensions.

Traditional, nonreactive particulate/fiber-based or settable fluid, types of loss circulation materials (LCMs), when applied in insufficient quantities, cannot effectively seal a high permeability zone. The LCM described in this article is, however, expandable in nature. This expandable nature of the resin can help the LCM adapt in volume to effectively seal a wide range of fractures with unknown dimensions. Volume adaptability is introduced in the LCM through in situ generation of gas due to the decomposition of a gas generating compound.

The novel expandable LCM comprises a resinous material, a gas producing agent, surfactant, and an activator. The resinous material, in the presence of a gas producing agent, surfactant, and an activator is designed to expand under downhole conditions and help to cure severe losses. Different LCM compositions comprising varying concentrations of resin material, a gas producing agent, surfactant, and an activator have been described in the article. Two different resins were used in the study. The resins were mixed in different ratios and the impact on gelling time was investigated. An aliphatic chemical activator was used in the study. The effect of this activator on the gelation properties of the resin was investigated. The effect of temperature on the expansion of the resin in the presence of a gas producing agent was also investigated.

The expandable LCM starts to generate gas in situ under wellbore conditions. Laboratory testing has been performed to quantify the percentage of expansion of the resin at different temperatures. It was observed that the rate of gas generation is faster at higher temperatures. The expandable LCM is designed so as to have a controllable gelation time under a variety of downhole conditions to allow accurate placement of the LCM inside the wellbore without premature setting of the fluid.

It was shown that the gelation time of the treatment composition could be controlled by adjusting the concentration of the activator. The system is designed so as to give a predictable and controllable pumping time, ranging from a few minutes to several hours over a wide range of temperatures.

Introduction

The loss of drilling fluids or cementing slurries into one or more of the surrounding geological formations is called loss of circulation[1]. Loss of circulation happens primarily in naturally fractured, weak, highly permeable or vugular formations[2]. Table 1[3] lists the rate of loss of circulation downhole, which may range from minor loss or seepage loss, severe loss and higher, to complete fluid loss. Due to loss of circulation, it is difficult for a drilling fluid to perform the various functions that is expected from it. Problems such as pipe sticking, borehole instability well control, formation damage due to plugging of pores and pore throats by mud particles, unsuccessful production tests, and poor hydrocarbon production, are some of the results of loss of circulation.

As a consequence of loss of circulation, valuable drilling time, and consequently, a lot of money is lost annually either to replace the fluids lost in the formation or to remediate the loss of circulation to avoid dangerous blowouts or stuck pipes[4].

Although the presence of lost circulation is a gracious sign showing pressure is under control, the petroleum industry spends millions of dollars annually. Typically, loss of circulation can be mitigated or prevented by introducing a material to seal off the lost circulation zones, thereby preventing further loss of drilling fluids into the formations[5]. Conventional lost circulation materials (LCM), such as fibrous materials, flaky materials, bridging agents, granular materials, and different blended particulates having different particle sizes and shapes are used to mitigate any loss of circulation[6, 7]. These conventional materials, though effective at solving seepage or partial losses, are ineffective in mitigating severe or total loss of circulation. This is due to the fact that when the fracture sizes are relatively larger, the conventional loss of circulation agents are unable to form an effective plug and seal

Table 1 The types and rates of loss of circulation downhole[3]*.*

Different Types of Loss of Circulation	Rate of Loss (bbl/hr)
Seepage	1 bbl/hr to 10 bbl/hr
Partial	10 bbl/hr to100 bbl/hr
Severe	> 100 bbl/hr
Total	> 500 bbl/hr

the loss of circulation zones[8].

This article describes the use of an expandable epoxy resin-based LCM to mitigate severe-to-total losses. Epoxy resins, which provide excellent physical properties, have zero solid content, are liquid in nature, and thereby allow deeper penetration in the formation as well as can be easily injected through the drill bit into the loss of circulation zones. The resins have high resistance against various solvents, are not susceptible to corrosion and can withstand high temperatures[9, 10]. Also, epoxy resin formulations provide short and controlled transition time from liquid to solid[11].

The expandable LCM, as described in the article, is primarily comprised of an epoxy resin, a curing agent, and a nitrogen generating additive. The expanding LCM has been designed to plug fracture sizes that are relatively larger in size so that it can form an effective plug and cure severe to total losses. The expandable LCM has been designed to give a controlled viscosity and pumping time.

This novel resin composition can remain in a liquid phase from a few minutes to several hours, based on the downhole conditions. This would allow accurate placement of the fluid inside the wellbore over a period of time. The final resin composition after curing will appear as a gelled and foamed solid, thereby preventing loss of circulation.

Materials and Methods

Two different types of epoxy resins viz. Epoxy Resin 1 and Epoxy Resin 2, have been used in the formulation of expandable resin. Epoxy Resin 1 comprises two epoxy groups, whereas Epoxy Resin 2 comprises of only one epoxy group. An aliphatic amine-based curing agent was used in the study.

The resin composition, which comprises an epoxy resin and a chemical activator, undergoes a polymerization reaction. No water or any other solvent was added in the formulation. The final polymeric resin should show an excellent heat resistance and chemical stability against corrosion and various solvents[9, 12]. The linear resin through the curing process gets converted into a 3D cross-linked resin. Such a polymerization reaction produces a rapid increase in the final slurry viscosity[13-15].

We have described three different resin formulations to study the polymerization time and process. This was done to develop a novel LCM that can be delayed and successfully controlled to become gel and form the target solid resin composition after the fluid goes inside the wellbore. This is very important to avoid early setting of the fluid.

A nitrogen gas generating additive has been used to produce nitrogen gas in situ to generate an expandable epoxy resin-based expandable LCM. A typical surfactant-based foamer has been used to stabilize the generated nitrogen gas in the expandable LCM formulation.

Experimental Section

The expandable resin-based LCM was developed using two different tests. The thickening or gelling time of the resin was determined using the thickening time tests while the ability of the resin to expand was tested through the expansion tests.

Thickening Time Test

A standard American Petroleum Institute (API) high-pressure, high temperature consistometer was used to evaluate the pumpability of the resin mixture. The consistometer is used to determine how long the resin formulation will remain in a fluid state in downhole conditions. The thickening time is the time taken by the resin mixture to reach a consistency of 70 Bc to 100 Bc.

The resin mixture is poured from the blender into an API slurry cup. The resin mixture is then placed in the consistometer and is then subsequently subjected to the required temperature and pressure.

Expansion Test

The expansion test was performed after mixing the resin and foamer in a graduated test tube, and then 15 ml of epoxy resin is taken in a graduated test tube. The required amount of curing agent was mixed for 1 minute. A nitrogen generating additive and a foamer was added into the epoxy resin mixture and gently mixed with the help of a spatula. The samples were then capped, and subsequently placed in a water bath. Volume expansion as a function of time was then noted.

Results and Discussion

Thickening Time Test

In this study, three different resin formulations were used to develop the novel LCM. Each formulation contains an epoxy resin mixed with a curing agent. Although, the type of epoxy resin as well as the amount of curing agent were changed in the formulations as given in Table 2. This was done to study the effect of the curing agent concentration and type of resin on the polymerization or curing reaction. This is important to accomplish a controlled and a delayed thickening time for the resin. Also, the curing time for the resin was evaluated by simulating downhole conditions (223 °F and 5,700 psi) to prove the effectiveness of this novel resin composition as a LCM.

Formulation 1 comprises 100 g of Epoxy Resin 1 and 3 g of a curing agent, Formulation 2 comprises 100 g of Epoxy Resin 1 and 1.5 g of a curing agent, and Formulation 3 comprises a mixture of Epoxy Resin 1 + Epoxy Resin 2 in an 80:20 ratio and 3 g of a curing agent.

A thickening time test using an API high-pressure, high temperature consistometer was performed on each

Table 2 *The thickening time of three different resin formulations under downhole conditions.*

	Test Variables	Thickening Time	Test Temperature and Pressure	Bc Final
Formulation 1	100 g Epoxy Resin 1 + 3 g Curing Agent	4:20 hr:min	223 °F and 5,700 psi	100 Bc
Formulation 2	100 g Epoxy Resin 1 + 1.5 g Curing Agent	11:33 hr:min	223 °F and 5,700 psi	100 Bc
Formulation 3	Mixture of Epoxy Resin 1 + Epoxy Resin 2 (80:20 ratio) + 3 g Curing Agent	5:45 hr:min	223 °F and 5,700 psi	100 Bc

resin formulation to determine the pumpability of the resin mixture and to measure the difference in curing time for the three formulations. Figures 1 to 3 show the thickening time charts for the three resin formulations, respectively.

As previously shown in Table 2, Formulation 1 with 3 g of a curing agent gives a thickening time of 4.20 hours, whereas Formulation 2 with 1.5 g of a curing agent gives a thickening time of 11.33 hours. This shows that the time required for the resin to cure is inversely proportional to the concentration of the curing agent. Also, a comparison of thickening times for Formulation 1 and 3 shows that Formulation 1 with an epoxy resin having two epoxy groups in its structure has a lower thickening time as compared to Formulation 3, which has 20% of the epoxy resin with one epoxy group in its structure. Mixing a lower amount of epoxy resin that contains one epoxy group with an epoxy resin with two epoxy groups in its structure can increase the gelling or thickening time; which is favorable in terms of mixing and pumping time. Also, Epoxy Resin 2 with its lower rheology, can also act as a diluent and lower the pump pressures while pumping the resin formulation in the wellbore.

These test results therefore show that it is possible to design a resin-based loss of circulation composition that provides a controlled pumping time. Depending on the concentration of the curing agent, the resin composition can remain in a liquid phase from a few minutes to several hours based on the downhole conditions. This would allow for the accurate placement of the resin inside the wellbore in the desired time period.

Expansion Test

The expansion test was performed by mixing 15 g of Epoxy Resin 1 and 0.45 g of a curing agent in a graduated test tube. A nitrogen gas generating additive and a foamer was then subsequently added to the test tube by gentle mixing. The resin formulation was then capped and kept in a water bath, preheated at 120 °F and 150 °F, respectively. The expansion of the resin was then noted as a function of time. Figure 4 is a typical picture of the

Fig. 1 *The thickening time test result of formulation 1.*

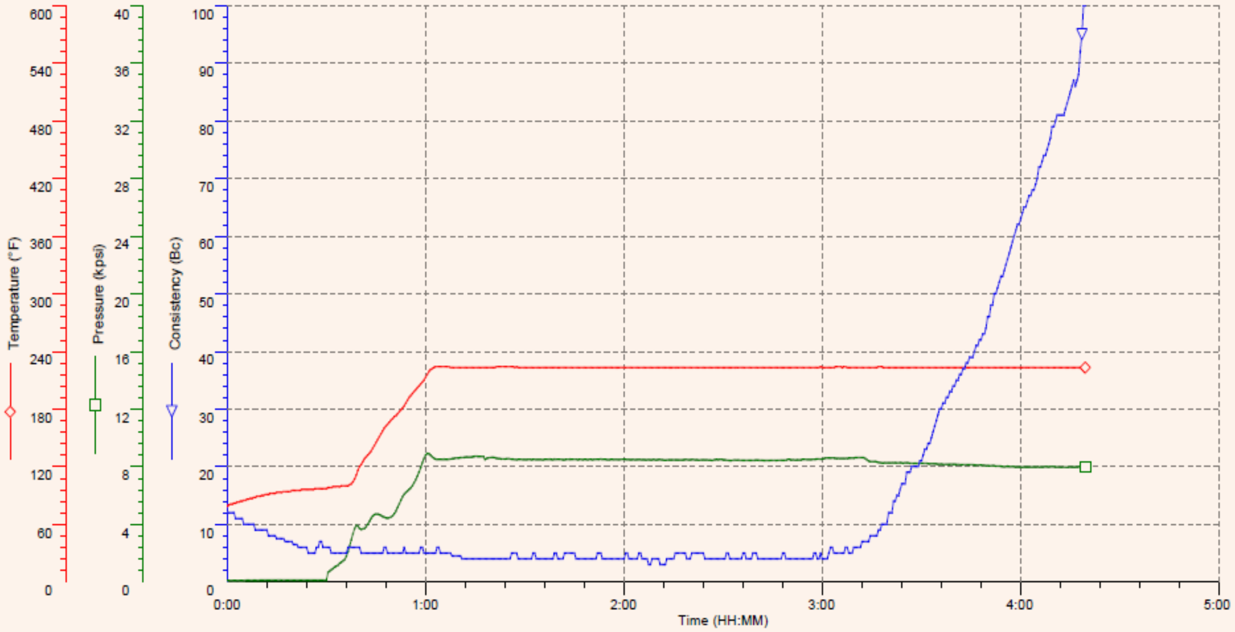


Fig. 2 *The thickening time test result of formulation 2.*

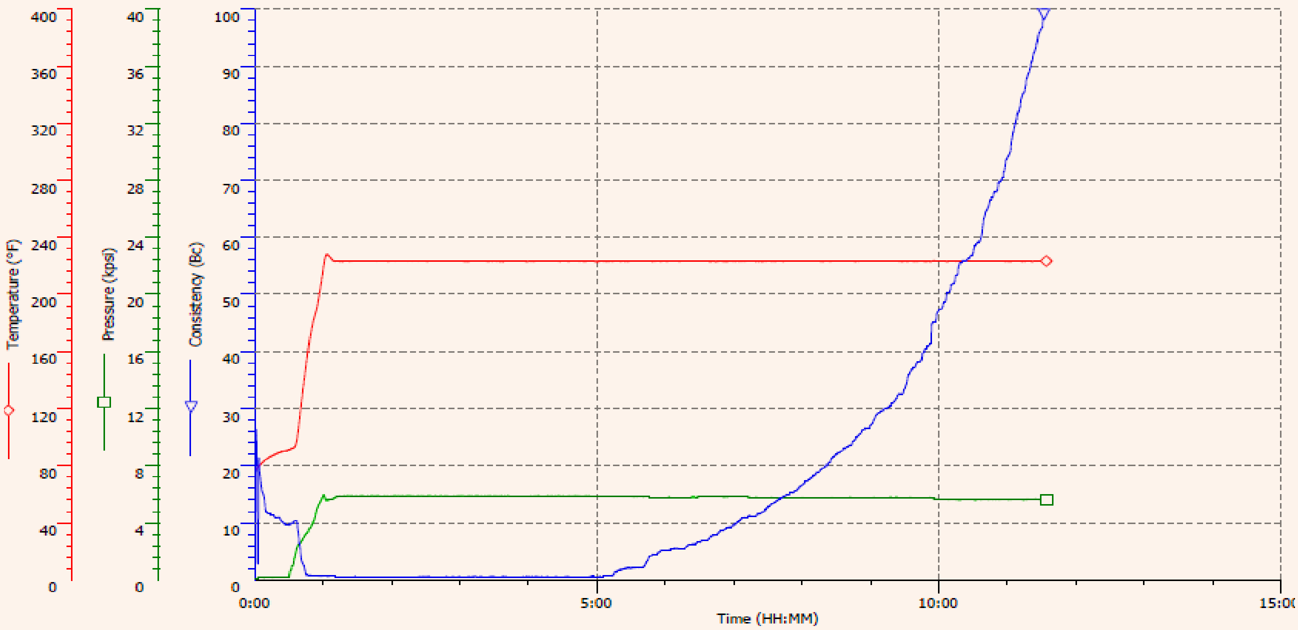
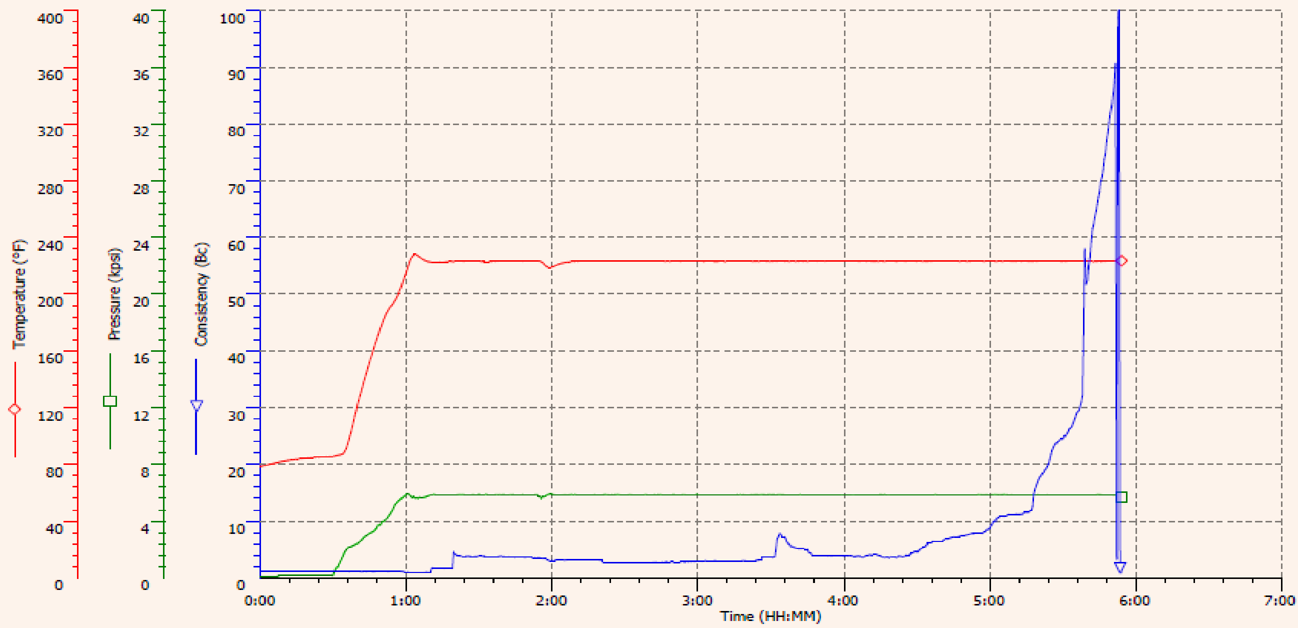


Fig. 3 *The thickening time test result of formulation 3.*



resin in the presence of a nitrogen generating additive.

Table 3 lists the volumetric expansion of the resin in the presence of the nitrogen generating additive at 120 °F and 150 °F, respectively.

As previously seen in Table 2, at 120 °F, the resin showed an expansion of 100% after 50 minutes, whereas at 150 °F, the resin expanded by 180% after 25 minutes of keeping the samples in the water bath. This shows that the rate at which the resin expands in the presence of the nitrogen generating additive is dependent on temperature, i.e., the higher the temperature, the higher the rate of decomposition of the nitrogen generating additive, and higher is nitrogen gas generated, and subsequently, the rate of expansion is higher.

Fig. 4 *The resin formulation in the presence of a nitrogen generating additive.*

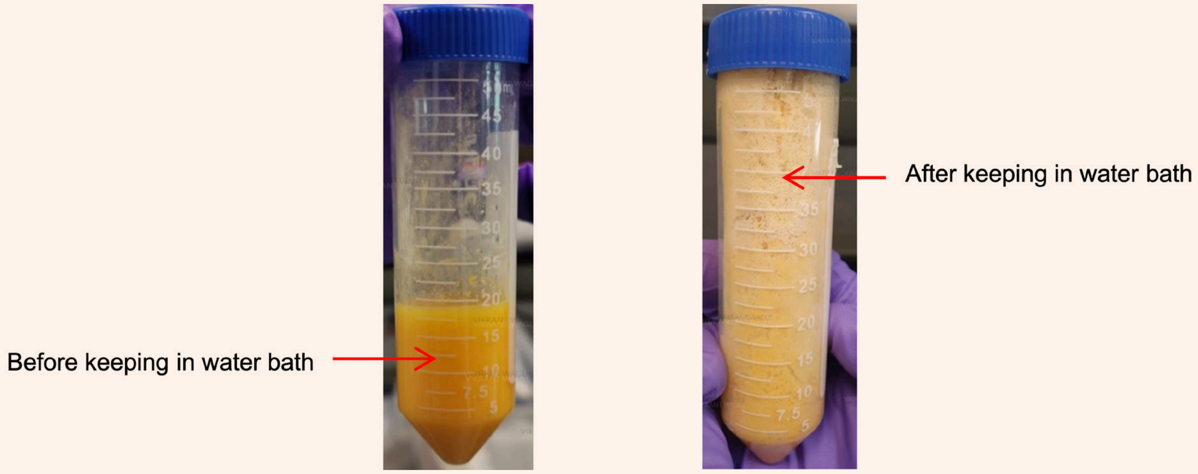


Table 3 *The volumetric expansion of Epoxy Resin 1 at 120 °F and 150 °F.*

120 °F			150 °F		
Time	**Volume**	**% Expansion**	**Time**	**Volume**	**% Expansion**
0	15	0.0	0	15	0.0
10	16	6.7	5	18	20.0
20	19	26.7	10	23	53.3
30	22	53.3	15	29	93.3
40	28	80.0	20	35	133.3
50	33	100.0	25	42	180.0

Field Placement Method for the Expandable Resin

The expandable resin can be deployed in the field to control loss of circulation as a one-component LCM. In the one-component method, the resin, curing agent, foamer, and nitrogen generating additive can be mixed on the surface and pumped downhole through an open ended drillpipe. The concentration of the curing agent can be adjusted depending upon the depth of the loss of the circulation zone.

The gelling time tests need to be completed at the desired temperature of the loss of circulation zone to decide upon the concentration of the activator. The activator concentration should be sufficient to cause gelling of the resin in the loss of circulation zone without resulting in premature gelling of the resin.

Conclusions

The expandable resin composition can be designed to have a controlled thickening time depending on the downhole conditions. This novel resin composition can remain in a liquid phase from a few minutes to several hours based on the desired conditions. This would allow accurate placement of the resin composition inside the wellbore; thereby avoiding an early setting of the resin composition.

The thickening time of the resin composition can be controlled by varying the type of resin, and also the concentration of the curing agent. The final resin composition, due to the decomposition of the nitrogen generating additive, will appear as an expanded solid, thereby preventing any loss of circulation. The extent of expansion can be controlled by varying the amount of the nitrogen gas generating agent.

Different types of particulates, fibers, weighting agents, etc., can be added to the resin composition to enhance its ability to cure any loss of circulation.

Acknowledgments

This article was presented at the Middle East Oil and Gas Show and Geosciences Conference and Exhibition, Manama, Kingdom of Bahrain, February 19-21, 2023.

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