A GEL DIVERTING AGENT USED IN ACIDIZING TREATMENTS

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INTRODUCTION

Diverting methods have been developed and used extensively to distribute treating fluids in a zone or to divert them from one zone to another. Diverting may be accomplished mechanically or chemically.

Mechanical diverting with perforation-sealing balls is a common procedure, but conditions may exist which make it ineffective. The height of the zone, number of perforations, limited pump rate, and capacity of the formation to take fluid are factors which may lower fluid velocity so that it is not adequate to seat the balls on the perforations. Communication between perforations or behind the casing, or perforations that are not round also may limit the effectiveness of ball sealers.

Packers also have provided effective mechanical diverting. However, they are more difficult to use because their effectiveness is dependent on accurately locating the zone to be treated and accurately setting the packer to isolate this zone.

Numerous soluble particulated solids, which are often referred to as temporary bridging agents, have been developed for fluid diversion. These are solid chemicals that have varying physical and chemical properties. An agent can usually be selected that is satisfactory for a specific treating operation. These diverting agents usually are transported in a viscous carrier fluid and are pumped between stages of treating fluid. The effectiveness is dependent on the strength and permeability of the bridge formed. Some solid diverters have a wide particle size distribution and form low permeability bridges, but their permeability is not low enough to effectively divert treating fluids to zones having a permeability less than about 2 md, and the need for an impermeable gel diverting system was recognized.

A gel diverting system, in order to be used as a diverter in acidizing treatments, has to meet the following criteria: the gel has to have a low viscosity during placement, hydrate to form a solid impermeable gel in the formation, revert with time to a liquid for removal, and leave a minimum of permeability damage.

Various chemical types of gelling agents were evaluated in order to obtain a feasible gel diverting system. On the basis of the gelation time and stability tests, only two gelling agents appeared to meet the necessary criteria. One of these gelling agents was a high-residue natural gum and the other was a low-residue modified natural gum. A gel diverting system using the low-residue gum was finally selected since the diverting-efficiency and permeability-recovery tests showed that using the high-residue gum resulted in permeability damage. So, only the data using the low-residue gel system are presented in this paper, except in the diverting-efficiency and permeability-recovery tests, in which case the data from tests using both the high and low-residue gums are presented.

The procedure used on a field job is presented, and the results are described.

GELLING AND BREAKING TIME TESTS

Laboratory Tests

The gelation time tests were conducted in order to determine if the gels could be pumped down the tubing and into the formation before gelation would occur. Viscosity development was measured to determine this gelation time. In these tests, the gel diverting agent was allowed to set at ambient conditions for 24 hours before gelation measurements were started, to simulate holding times that might be encountered in field operation. Measurements were made using a Model 50B Fann Viscometer with 500 psi N_2 pressure. Viscosity was recorded as the temperature was increased from 80° F at a rate of 5 to 10° F/minute. This thermal rise in the gel temperature simulated the thermal effect that occurs when the gel is displaced down the tubing. The gelation time data given in Table 1 represent the maximum amount of placement time available under the test conditions.

TABLE 1 —GELLING AND BREAKING TIME LABORATORY TESTS

Test Temperature (80°F to)	Rate of Thermal Rise (°F/min)	Lb Stabilizer/ 1000 Gal	Gelling Time (Min)	Breaking Time (Hours)
180	5	0	125	672+
215	5	0	36	672+
230	5	0	38	672+
250	5	0	37	336
285	7	0	35	66
285	7	50	35	66
285	7	100	36	66
285	7	200	40	144
285	7	300	44	216
285	7	400	43	240
285	7	500	45	184
300	8	0	--	36
300	8	500	27	96
350	10	0	--	5
350	10	500	22	36

Breaking time tests were performed to determine the length of time the gel would be stable at the bottomhole temperature. Breaking time tests were determined by placing aliquots of the gel in pressure cells at 200 psi N_2 pressure. The cells were then placed in hot oil baths and observed. The breaking time listed is the time required for the gel to break to a pourable fluid upon tilting the aliquot. The breaking time test cell is shown in Fig. 1.

Results

Results of the gelling time and breaking time tests are given in Table 1. These gelling time results indicate that a cooling preflush should be considered to obtain adequate placement time if the formation temperature exceeds about 200° F.

Breaking test results show the gel diverting agent

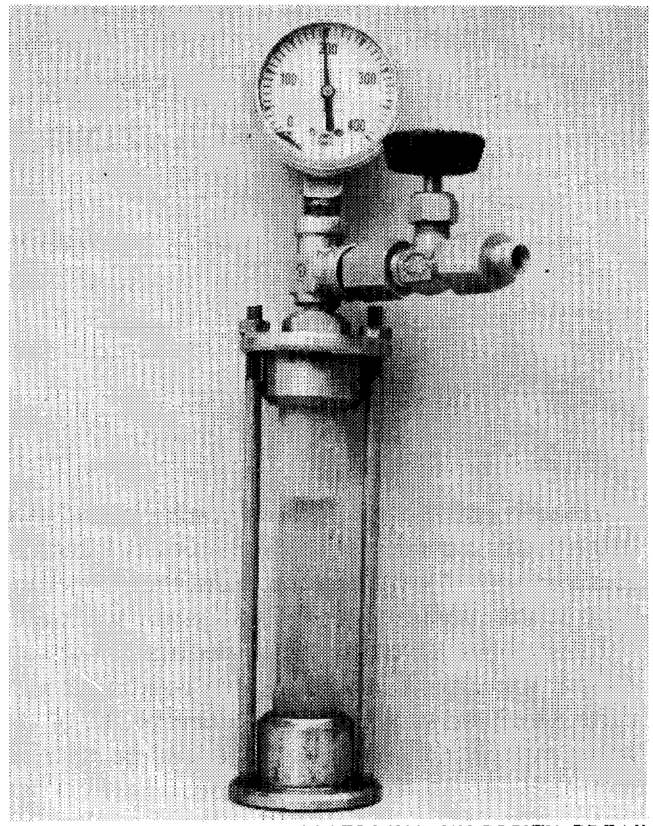


FIG. 1 TEST CELL FOR OBSERVING VISCOSITY BREAK TIMES

is stable at temperatures up to 250° F without any additional additives. Thus, this gel diverter system could be used as a sealing agent for lost circulation zones for extended periods or for long-term workover operations up to 250° F. Above 250° F, this gel system has a breaking time short enough for it to be used as a diverting plug in acidizing treatments. This gel will break upon contact with acid; but in diverting an acid treatment, the gel plug will be in place in the formation, so only a small portion of the gel is contacted by the acid.

A stabilizer can be added to the gel system which makes the gel resistant to breaking upon contact with acid. The effect of this stabilizer on increasing the acid resistance of the gel is given later in the text.

Another effect the stabilizer has on the gel is to increase the breaking time of the gel. As can be seen in Table 1, increasing the concentration of the stabilizer from 50 to 500 lb/1000 gallons, increased the breaking time from 66 hours to 288 hours at 285° F and provided a breaking time of 96 hours at 300° F and 36 hours at 350° F. However, the addition of the stabilizer to the gel system does not increase the gelation time. So, in wells above 200°F, a cooling preflush should still be used to obtain adequate placement time.

DIVERTING EFFICIENCY AND PERMEABILITY DAMAGE

Laboratory Tests

Diverting tests were conducted with gel diverters made with high and low-residue gums to determine diverting efficiency and permeability damage that might occur when using either gel system to divert an acid treatment.

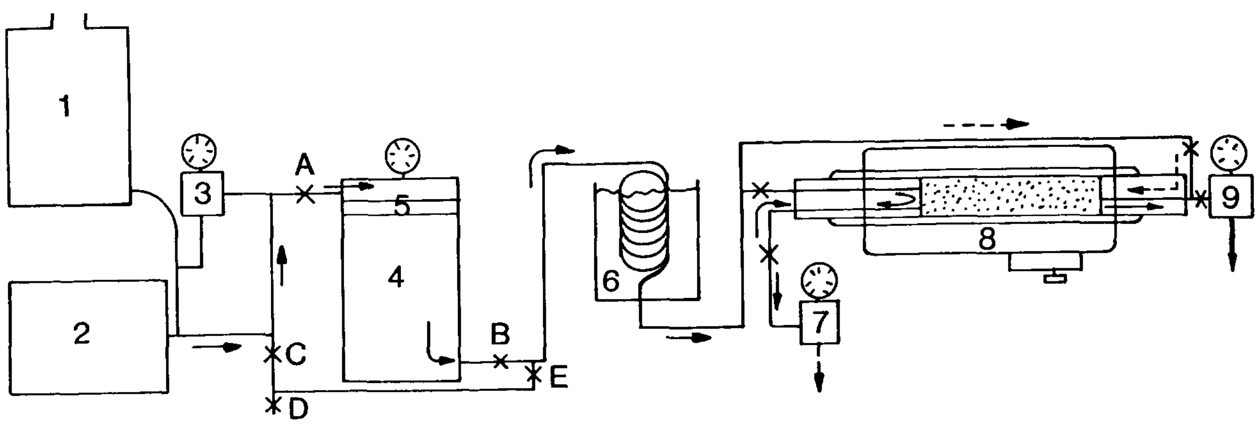
These diverting tests were conducted using Bedford Indiana limestone cores having a diameter of 1-3/4 in. and a length of 2-1/2 in. The brine permeability of the cores ranged from 20 to 25 md. The core was placed in a Hassler sleeve that was mounted in an electric heating jacket set at 285°F. Two hours were allowed for the equipment to stabilize at 285°F. The equipment arrangement is shown in Fig. 2.

Three diverting tests were conducted, and the data are shown in Table 2. Tests No. 1 and No. 2 were conducted using 100 psi in all phases of the test. These tests compare the diverting and clean-up properties of natural gum gelling agent that produces about 10 percent residue, and modified gum gelling agent that produces about one percent residue.

Test No. 3 was conducted to compare the diverting and clean-up properties of the low-residue gelling agent at 100 psi and 1600 psi. Test No. 3 was conducted using the same procedure used in Test No. 2 with one exception; the gel which had hydrated 64 hours was subjected to 1600 psi in Test No. 3.

In these tests, initial brine permeability was measured by pumping brine to the core through coiled tubing which was immersed in a 180°F bath. The brine was pumped at 400 psi, and a back-pressure regulator on the back side of the core was set at 300 psi to maintain 100 psi differential pressure across the core. Kerosine permeability, with residual brine in the core, was measured. Brine permeability was then measured with residual oil in the core.

The low-viscosity gel diverting agent was pumped through a coiled tubing which was immersed in a 180°F bath, then to a Hassler sleeve containing the core which was at a temperature of 285°F. The gel was injected into the core to the degree it was



1. KEROSINE RESERVOIR
2. WHITEY PUMP
3. BACK-PRESSURE REGULATOR (400PSI)
4. BRINE OR ACID RESERVOIR
5. FLOATING PISTON
6. OIL BATH
7. BACK-PRESSURE REGULATOR (300PSI)
8. HASSLER SLEEVE WITH CORE IN HEATING JACKET
9. BACK-PRESSURE REGULATOR (300PSI)

→ FORWARD FLOW
→ BACK FLOW

FIG. 2 EQUIPMENT ARRANGEMENT TO DETERMINE DIVERTING EFFICIENCY AND PERMEABILITY DAMAGE accepted, and then the gel was held on the core at 100 psi pressure for 64 hours. The flow rate into the core was measured at 100 psi differential pressure in Tests No. 1 and No. 2 and 1600 psi differential pressure in Test. No. 3 using the gel diverting agent, and the permeability was calculated. The gel was displaced from the flow lines and cell with brine, and brine was flushed across the face of the core. Flow rates were measured in recovery tests at 100 psi differential pressure by flowing brine forward at 180°F, backflowing brine at 285°F, and backflowing kerosine at 285°F. Kerosine flow rates were measured at 0, 2, 16, and 24 hours, and the permeabilities were calculated. Calculated permeability damage was based on the initial kerosine permeability and the final kerosine permeability, after backflowing 24 hours. Data are presented in Table 2.

Results

The results of the diverting efficiency flow tests indicate that the diverter will temporarily seal a zone completely. The results of backflow tests with kerosine indicate the selection of gelling agent is important. The regular gum showed 50 percent permeability damage, and the low-residue modified gum showed 0 percent permeability damage. The backflow tests with brine did not remove damage that resulted from both gelling agents as effectively as kerosine.

EFFECT OF STABILIZER ON ACID RESISTANCE

Diverting tests were conducted to determine the effect of various concentrations of stabilizer on the gel's resistance to breaking by acid treating solutions.

The Hassler sleeve previously described was used in an upright position. The head on the sleeve was hollow so that a three-inch gel plug could be placed on the core and 15% HCl held on the gel plug until the acid broke through the gel and core. Tests were conducted at 180°F, using 100 psi and 500 psi differential pressure across the core. The results of these tests, as shown in Table 3, show that the addition of the stabilizer to the gel system can significantly increase the gel's resistance to acid breaking.

TABLE 2—EFFECT OF GUM SELECTION AND PRESSURE ON DIVERTING EFFICIENCY AND PERMEABILITY DAMAGE

Conditions: Temperature of Sleeve and Core - 285°F
Temperature of Oil Bath (Forward Flow) - 180°F
Temperature of Oil Bath (Backflow) - 285°F
Formation - Bedford Indiana Limestone
Core Dimension - 2 1/2" L x 1 3/4" D

	Permeability (mds)		
Fluid Sequence*	Test No. 1 10% Residue Gum	Test No. 2 1% Residue Gum	Test No. 3 1% Residue Gum
Standard Brine	25.0	20.0	22.0
Kerosine	23.0	10.8	16.0
Standard Brine	17.0	4.5	7.0
Gel	Nil	Nil	Nil
Gel Hydrated 64 Hours**	Nil	Nil	Nil
Standard Brine, Initial Perm.	8.3	1.8	1.6
Standard Brine, Perm. After 24 Hours	3.3	1.0	1.2
Standard Brine(pH-5.7) Initial Backflow Perm.	3.3	3.1	1.6
Standard Brine(pH-5.7) Backflow Perm. After 24 hours	2.4	0.2	1.1
Kerosine Initial Backflow Perm.	1.8	4.0	0.8
Kerosine Backflow Perm. After 2 hours	2.5	5.7	2.5
Kerosine Backflow Perm. After 16 hours	8.2	10.5	14.6
Kerosine Backflow Perm. After 24 hours	11.4	10.8	16.0
Perm. Damage	50%	0%	0%

*The fluid was flowed forward through the core unless indicated as backflow.

**This measurement was made in Tests No. 1 and No. 2 at 100 psi and in Test No. 3 at 1600 psi.

FIELD TEST PROCEDURE AND RESULTS

A gel diverting treatment was designed to treat 200 ft of 285°F limestone formation at a depth of 15,650-15,850 ft that was divided into seven zones because of permeabilities that ranged from 2-250 md. The well had been previously treated with 7000 gal. 15% HCl.

TABLE 3—EFFECT OF GEL STABILIZER ON ACID RESISTANCE

Conditions: Temperature - 180°F
Formation - Bedford Indiana Limestone
Core Dimension - 2 1/2" L x 1 3/4" D
Gel Plug - 3 inch

Gel Stabilizer Lbs/1000 Gals	Hydration Time and Temperature	Acid Break Thru Time 100 psi ΔP	Acid Break Thru Time 500 psi ΔP
50	2 hours at 180°F	6 hrs.	4 hrs.
100	2 hours at 180°F	18 hrs.	12 hrs.
200	2 hours at 285°F	25 hrs.	18 hrs.
500	2 hours at 285°F	48 hrs.+	36 hrs.

Two days were to be required to complete the treating operation; therefore, the gel diverter was designed to hydrate to form a solid gel in place and remain solid for 66 hours.

The initial step was to pump 150 bbl cooling preflush water to cool the formation to 180° F. This was followed by 1000 gal. gel diverting agent. The gel was displaced into the formation with oil and was allowed to hydrate for one hour to a solid. The gel plug was pressure-checked to 1000 psi. Sixty barrels of cooling preflush water were pumped and followed by 1000 gal. gel diverting agent to seal off highly permeable zones missed by the first plug. A pressure check was made, and a pressure increase of 1600 psi was obtained. The second plug was followed by 3000 gal. 15% HCl. The acid was followed by two barrels of gel containing radioactive sand to determine the zones that were treated with acid.

On the second day, 150 bbl preflush water were pumped ahead of 1000 gal. gel diverting agent to cool the wellbore to 180° F. The gel was displaced into the formation with oil and was allowed to hydrate for one hour. A pressure check showed a 1200 psi increase in pumping pressure. The gel was followed by 3000 gal. 15% HCl. The acid was followed by two barrels of gel containing radioactive sand. One thousand gallons of gel diverting agent were then pumped into place, were allowed to hydrate one hour, and pressure-checked to 1200 psi. The diverting agent was followed by acid and gel containing radioactive sand. Finally, 1000 gal. gel diverting agent were pumped and followed by 3000 gal. 15% HCl and two barrels of gel containing radioactive sand.

The well was opened up 76 hours after the initial gel plug was pumped (this would be 52 hours after the final gel plug was pumped). The well started cleaning up immediately and cleaned up quickly.

A gamma log was run, and the results showed that the radioactive sand, which followed each stage of acid, had gone into all perforations in the seven zones. A spinner survey showed production coming from all zones except the one with the lowest permeability. A third study indicated this zone was also producing a small amount of fluid.

CONCLUSIONS

1. Adequate placement time is provided by this gel system at temperatures up to 200°F without a cooling preflush.
2. The gel hydrates in place to form an impermeable solid that diverts effectively.
3. The gel plug has sufficient stability for effective diverting at temperatures up to 350° F.
4. The flow test data indicate that the low-residue gelling agent cleans up more readily than regular gum.
5. A stabilizing agent may be added to the gel system to make the gel plug more temperature-stable and more resistant to acid penetration.
6. This gel diverting agent warrants consideration for sealing off zones in stimulation and workover operations.
7. This gel diverter warrants consideration for sealing lost circulation zones.

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