The Use of Temporary Blocking Agents in Fracturing and Acidizing Operations†

GARLAND L WHITE*

ABSTRACT

Because the use of temporary blocking agents has greatly simplified and increased the effectiveness of fracturing and acidizing operations, it was believed that a resume of these materials and their application to well stimulation would be of general interest to those involved in the petroleum-production industry.

Temporary blocking agents are classified as bridging materials and deep-sealing agents. Graded granular materials and perforation-sealing balls are discussed as bridging materials. The characteristics of four granular materials (viz., naphthalene, walnut shells and resin, ammonium chloride in gelled kerosene, and rock salt) are discussed. The three types of perforation-sealing balls are compared. The deep-sealing heavy-metal soap-kerosene gel block is discussed.

Factors considered most important in choosing a temporary blocking agent are: type of formation, openings to be blocked, temperature and pressure, local experience, and type of completion.

INTRODUCTION

Selective acidizing or fracturing can be defined as the treatment of one zone or a section of a producing zone in preference to another. Prior to the introduction of temporary blocking and bridging agents, this was a rather complicated operation and, frequently, not a very efficient one. First, the interval to be treated had to be located. Then it had to be isolated from the permeable sections, usually by means of a packer or bridge plugs. Temporary blocking and bridging agents greatly simplify the operation by isolating the permeable section to be excluded as the treatment is in progress. When several zones or sections of a zone are selectively treated by alternating batches of treatment fluid and temporary blocking material in order to obtain better permeability distribution, the operation is known as multiple fracturing or acidizing.

CLASSIFICATION OF TEMPORARY BLOCKING AGENTS

It is probable that as many temporary blocking agents have been used in acidizing and fracturing as have been tried for the control of lost circulation. Indeed, the mechanics of this type of block are essentially the same as those used for the control of lost circulation. Only in one important way do they differ. Temporary blocking is usually for a very short period with no permanent reduction in permeability. Lost-circulation blocking is usually for a long period or is permanent.

Temporary blocking materials can be classified according to their blocking mechanics. They are 1. materials which block by bridging at or near the well bore and affect an impermeable seal, and 2. those which are pumped relatively far back into the formation as a fluid and develop a gel structure to plug off the permeability. The former types are less expensive, do not always require extra mixing equipment, and might be expected to withstand higher treating pressures. The latter give a positive seal both away from and toward the well bore, lessen the danger of communication during the treatment, and can be formulated to retain a block for a longer time.

Several authors, 1, 2, 3, 5 have pointed out the effectiveness of graded, granular materials as blocking agents to combat lost circulation. These materials have been used quite effectively for temporary blocking. Another blocking agent which has found wide application is the heavy-metal soap-kerosene gel. A recent development in temporary blocking has been the use of nylon, hard rubber, or rubber-covered nylon balls in perforated pay sections. Listing these materials according to type of block obtained gives:

Bridging Temporary Blocking Agents
A. Graded, granular material
B. Perforation bridging balls
Deep Sealing Temporary Blocking Agents
A. Heavy-metal soap-kerosene gel

A discussion of these temporary blocking agents most commonly being used might be pertinent to their consideration in well stimulation.

References are at the end of the paper.
DISCUSSION OF BLOCKING AGENTS

Graded, Granular Material

Because of their gradation from small to large particles, their strength, and their nearly equal dimensions in all directions, granular materials are better blocking agents than other solid materials such as flakes, fibers, and chips. This has been proved by Howard and Scott by slot-blocking tests. The results of these tests are shown in Fig. 1. However, this work was done with particles of equal gradation. Tests using wedge-shaped openings, which are more indicative of actual conditions, and with various gradations of each material might show that lesser quantities of bridging materials than indicated in Fig. 1 are required for larger openings. It also might be determined that materials with smaller maximum-sized particles would be more efficient for smaller fractures.

Fig. 2 illustrates how particles bridge a fracture to give positive blocking. The larger granules, either uniformly mixed in the slurry or slightly concentrated by settling in the lower portion, are forced into the formation opening until they bridge in a constriction. Slightly smaller particles bridge the openings left by the large particles and this action proceeds until all openings are closed, thereby producing an impermeable block.

In acidizing and fracturing treatments granular material is mixed in lease crude, the treating fluid, or a specially prepared viscous carrier. This slurry is pumped ahead of the treatment, or is alternated with the treating fluid in batches. The characteristics and limitations of the most used agents will be considered following.

1. Naphthalene

Naphthalene is a solid aromatic hydrocarbon with a melting point of 176°F and a specific gravity of 1.145. The material used for temporary blocking is known as TLC-C2 and is coated to prevent caking in storage. The particles range from small granules to fairly large pellets. The screen analysis of a typical lot is given as follows:

<table>
<thead>
<tr>
<th>U.S. Screen No.</th>
<th>Percent Retained</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>66.8</td>
<td>66.8</td>
</tr>
<tr>
<td>8</td>
<td>29.2</td>
<td>96.0</td>
</tr>
<tr>
<td>10</td>
<td>1.3</td>
<td>97.3</td>
</tr>
<tr>
<td>16</td>
<td>1.2</td>
<td>98.5</td>
</tr>
</tbody>
</table>

Naphthalene is soluble in kerosene, diesel, crude oil, and refined fracturing oil. The solubility increases as the temperature rises, and is greater in lighter hydrocarbons. This is demonstrated in Table 1.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Time for Complete Dissolution*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil, 47 API</td>
<td>2 hours, 70°F, 100°F, 120°F</td>
</tr>
<tr>
<td>Crude oil, 24 API</td>
<td>7 days. 2½ hours, 14 min.</td>
</tr>
<tr>
<td>Refined fracturing oil</td>
<td>3 hours, 50 min.</td>
</tr>
<tr>
<td>Kerosene</td>
<td>11 min. 5 min.</td>
</tr>
</tbody>
</table>

*At a concentration of 2 lb per gal

Its solubility is very important when considering this material as a blocking agent. When used in hydrocarbon carriers at higher temperatures, higher concentrations should be used to compensate for solubility losses.

Granular naphthalene should not be used in the metallic soap gels because of its greater solubility in kerosene. It can be used in lease oil, acid in oil emulsions, refined fracturing oil, and gelled lease oil.

2. Walnut-shell Resin Mixture

This blocking material is composed of 25-percent walnut shells and 75-percent oil-soluble resin. The physical characteristics of the material, as given by Purswell, are listed in Table 2.

The solubility of the resin in this material also increases with temperature, and this must be taken into consideration when determining the concentration to use. It is not as soluble in kerosene as naphthalene, therefore it probably could be used in the metallic soap gel as well as the other carriers.
Table 2

Physical Characteristics of Resin Walnut-shell Mixture*

<table>
<thead>
<tr>
<th></th>
<th>Walnut Shells</th>
<th>Resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Form</td>
<td>Granular solid</td>
<td>Granular solid</td>
</tr>
<tr>
<td>2 Percentage by weight</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>3 Specific gravity</td>
<td>1.25-1.40</td>
<td>1.1</td>
</tr>
<tr>
<td>4 Sieve analysis</td>
<td>-8 +16</td>
<td>293 F</td>
</tr>
<tr>
<td>5 Melting point</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>6 Compaction in storage</td>
<td>Soluble in kerosene and most</td>
<td></td>
</tr>
<tr>
<td>7 Solubility</td>
<td>Insoluble in water, acid, and oil</td>
<td>Insoluble in water and acid</td>
</tr>
</tbody>
</table>

*From Pauszek, Petroleum Engineer, June (1956)

3 Ammonium-chloride Pellets and Fines in Thickened Kerosene

Graded ammonium-chloride pellets or granules slurried in a sodium soap-kerosene gel have been used successfully as a temporary blocking agent. Other fine materials may be added to give more positive blocking and assist in thinning the gel. The function of the gel is to suspend the ammonium chloride. The pellets or granules range from -2 to +60 mesh and have a specific gravity of 1.53. Ammonium chloride is insoluble in oil, but soluble in formation water, and because of its high gravity any pellets not dissolved should fall to the bottom of the well after the pressure has been released.

4 Rock Salt

Rock salt has recently been utilized as a temporary blocking agent. The salt can be supplied in sizes from -4 to +30 mesh. The choice of concentration and particle size to use is based on the carrier. When fresh water, brine, or hydrochloric acid is used as a carrier, larger sizes and concentrations should be used because of the solubility of the salt in aqueous media. This solubility for various brines and acid concentrations is shown in Fig. 3. When rock salt is used as a temporary blocking agent in water fracturing and multiple acidizing, the block is dissolved by the returning aqueous fluid. When used in oil fracturing, formation water and the high specific gravity of the salt (2.16) must be depended upon to remove the block.

Heavy-metal Soap-kerosene Gel

There have been two types of temporary blocking gels used. They are the water-base gels and the hydrocarbon-base gels. The hydrocarbon-base gels have generally proved more satisfactory because they do not develop gel structure so rapidly as do water gels. This allows the hydrocarbon gel to be injected into the formation before its maximum blocking viscosity has been reached, whereas the water gel is injected at or near its maximum viscosity. Therefore, the hydrocarbon gel can be formulated to reach a much higher blocking viscosity. This difference in gelling rate is illustrated in Fig. 4. The viscosities were obtained at 100 F on a Brookfield HBF viscometer using spindle #4 at 1 rpm.

Fig. 3—Solubility of Rock Salt in Various Liquids

The hydrocarbon gels are usually of the heavy-metal soap-kerosene type. Crude oil could be used as the base fluid, but this is not good practice, as much as a small variation in the composition of the hydrocarbon causes a great variation in the gel characteristics. Diesel oil could also be used, but it makes a less satisfactory gel than does kerosene.

The kerosene to be used should be carefully chosen. The property of the kerosene which most affects the gel characteristics is its solvency. The solvency is indicated by the determination of the Kauri-Butanol number of the kerosene. The rate of gellation, Fig. 5, especially at temperatures below 125 F, is increased with increasing solvency (Kauri-Butanol number).

Fig. 4—Gellation Characteristics of Water-base and Hydrocarbon-base Gels
The heavy-metal soap powder used is especially manufactured and tested for this gel. A gel breaker and an acid-soluble weighting material are also incorporated in the gel. The density may be varied with weighting material, but is generally 7.5 lb per gal. Mixtures formulated for temperatures less than 100°F contain a gel accelerator.

A characteristic curve of apparent viscosity vs time is shown in Fig. 6. The gel may be pumped at any time before maximum pumpable viscosity has been reached. It should be displaced into the formation before blocking viscosity (approximately 500,000 centipoises Brookfield) has been reached. The time at blocking viscosity may be varied from 1/2 hour to several days according to requirements and bottom-hole temperature. The gel viscosity then continues to decrease to almost the original viscosity of the kerosene and can be removed from the well by the produced oil.

This gel is used in somewhat the same manner as the granular material. Because gel characteristics are greatly affected by temperature (Fig. 7), a specially compounded gel for the bottom-hole temperature at which it is to be used is mixed on the location. When the gel has reached a suitable consistency as dictated by the formation characteristics, it is pumped in the formation and given time to reach a blocking viscosity. The treatment may then be completed, or batches of gel may be sandwiched in between several treatments. This material cannot be used in wells having a bottom-hole temperature greater than 220°F. Bridging material may be incorporated in the gel. Such material should be added to the last part of the batch of gel in order to obtain both deep sealing and bridging.

Probably the biggest advantage in the use of the heavy-metal soap-kerosene gel is that when it is properly used it not only causes injected fluids to leave the well bore at a new place, but offers some control over the injected fluid after it leaves the well bore. Injected fluid which is diverted to a new opening in the well bore because the perforations are sealed or because an accumulation of solid bridging agents are blocking a formation opening might easily re-enter the blocked channel a short distance back in the formation. However, if the old channel is filled with extremely thick gel, the injected fluid can be diverted at least to the depth the gel has penetrated.

Fig. 6—Viscosity Characteristics of a Heavy-metal Soap-kerosene Gel
the well against the treating pressure had to be devised and tested.

It was generally agreed that perforation-sealing balls should have the following characteristics:
1. A density slightly greater than the heaviest fluid to be used.
2. Sufficient resiliency to seal irregularities in the perforations.
3. Sufficient rigidity to prevent extrusion through perforations.
4. Be inert to treating and formation fluids.

A comparison of the three types of balls — hard rubber, nylon, and rubber-covered nylon (Table 3) — now being used indicates that the rubber-covered nylon balls more nearly fulfill these requirements.

### Table 3
Properties of Perforation-sealing Balls

<table>
<thead>
<tr>
<th></th>
<th>Solid Rubber</th>
<th>Solid Nylon</th>
<th>Rubber-covered Nylon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter, in.</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
</tr>
<tr>
<td>Method of manufacture</td>
<td>moulded</td>
<td>machined</td>
<td>machined core</td>
</tr>
<tr>
<td>Catch efficiency</td>
<td>1.28</td>
<td>1.14</td>
<td>good</td>
</tr>
<tr>
<td>(low injection)</td>
<td>fair</td>
<td>good</td>
<td>excellent</td>
</tr>
<tr>
<td>(above 294 ft per min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sealing ability</td>
<td>excellent</td>
<td>fair</td>
<td>good</td>
</tr>
<tr>
<td>Resistance to oil</td>
<td>good</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>Resistance to acid below 150 F.</td>
<td>excellent</td>
<td>excellent</td>
<td>good</td>
</tr>
<tr>
<td>Resistance to acid above 150 F.</td>
<td>excellent</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>Cover bonding</td>
<td>fair</td>
<td>good</td>
<td>excellent</td>
</tr>
</tbody>
</table>
The balls may be introduced into the fluid stream by a number of methods. They may be injected one at a time from an injector tube (Fig 8) by means of hydraulic pressure or they may be introduced through a lubricator or a similar device in batches. The manually operated injector (Fig 8) or the power-driven injector (Fig 9) offer the advantage of introducing the balls singly at desired intervals for better "catch" efficiency.

The method of treatment with perforation-sealing balls is fairly simple. After the treating fluid has been started, a predetermined number of balls—usually 95 percent of the number of perforations—are begun to be added to the system. It is generally recommended that the balls be distributed equally throughout the treatment. This should allow each perforation to be opened and to accept an equal portion of treating fluid. After the treatment has been completed, pressure is released, and the balls drop to the bottom of the well.

FACTORS AFFECTING THE CHOICE OF A BLOCKING AGENT

The blocking agent for a selective or multiple acidizing or fracturing treatment should be as carefully chosen and engineered as the treatment itself. The cost of the material is important, but not a prime factor. An expensive treatment could be lost by using insufficient or poorly chosen blocking material.

Type of Formation

Howard and Scott classified formations capable of causing lost circulation as:

1. Natural or intrinsic fractures
2. Induced or created fractures
3. Cavernous formations (crevices and channel)
4. Unconsolidated or highly permeable formations (loose gravels)

The latter two are of little importance in a discussion of blocking agents, because they are rarely petroleum reservoirs. The open producing zones to be selectively blocked are nearly always natural or created fractures. When unconsolidated or vugular formations are encountered, the hydrocarbon gel is probably the best blocking agent to use.

The nature of the rock and the matrix permeability should also be considered when choosing a temporary blocking agent. It is well known that less pressure is required to institute a fracture in a more permeable section, because the fluid can penetrate the matrix and transmit the hydraulic pressure in the direction necessary to separate the formation. Also, the more permeable rocks generally are less cemented, and thus have less strength.

Openings to be Blocked

Inasmuch as it seems logical that the well-bore openings to be blocked are usually fractured ones, the determination of the width and distribution of the fractures would be useful to the choice of the kind and amount of temporary blocking material. Permeability surveys should indicate the magnitude and location of the fluid-accepting fractures, and will, if taken before and after the treatment, give an indication of the success of the treatment.

A zone having one large fracture might require only an initial treatment with a granular material, whereas one with large and small fractures might be more efficiently blocked by a combination of granular particles and heavy-metal soap-kerosene gel.

Temperature and Pressure

The bottom-hole temperature is a very important consideration when determining the type and amount of temporary blocking material. Temperature greatly affects the solubility of the organic bridging materials (naphthalene, resin) but only slightly affects the inorganic material (rock salt, ammonium chloride). This effect can be offset somewhat by using a carrier in which the material is insoluble. However, naphthalene, and to some extent, the resin, depends partly on the softening effect of the carrier to affect a block. Rock salt can be, and the beaded ammonium chloride is, slurried in hydrocarbon. Temperature also greatly affects the metallic soap-kerosene gel, and it can not be used above 220°F. High temperature adversely affects both the hard rubber and nylon balls (Table 3).

The bridging agents will withstand higher treating pressures than will the metallic soap-kerosene gel. However, the gel has the advantage of sealing the well bore from formation pressure. This allows pressure shut-down during a treatment, and in some cases prevents having to "kill" the well in order to run tubing or pump rods.

Local Experience

One of the most valuable aids an operator has in selecting a blocking agent is the experience gained in his area. In an area where selective and multiple fracturing and acidizing have been successfully applied, the first agent considered should be that which has proved most successful in that area, unless specific well characteristics vary greatly. Three examples of temporary blocking agents applied successfully in specific areas are 1, resin walnut-shell mixture reported used with good results in the Rocky Mountain area, 2, successful application of ammonium chloride in sodium soap-kerosene gel in the Texas Panhandle, and 3, fracture of 19 wells in Garfield County, Oklahoma, with metallic soap-kerosene gel with an average 15.4 bbl of oil per day or 770 percent increase.

Type of Completion

As has been pointed out, the perforation-sealing balls are only applicable as blocking agents in perforated casing. However, they are very probably the best of the blocking agents for this type completion unless there is communication behind the pipe or in the formation. Granular materials, metallic soap-kerosene gel, or a combination of both may be used on open-hole completions and in perforations.
CONCLUSIONS

1. Selective and multiple acidizing and fracturing treatments have been greatly simplified through the use of temporary blocking agents.

2. Temporary blocking agents can be classified as 1, those which bridge formation openings and form an impermeable block, and 2, those which are injected into the formation and develop a gel structure to seal off the permeability.

3. The most commonly used temporary blocking agents are:
   a. Graded granular materials
      1. Granulated naphthalene
      2. Resin walnut shells
      3. Ammonium-chloride pellets or granules
      4. Rock salt
   b. Perforation-sealing balls — hard rubber, nylon, rubber-covered nylon
   c. Deep-sealing agents
      1. Heavy-metal soap-kerosene gel

4. The graded granular materials and perforation-sealing balls are simpler to use and will withstand higher treating pressures, whereas the deep-sealing gel prevents communications during the treatment, seals the well bore from formation pressure and fluids, and can be formulated to retain the block for a longer time.

5. The physical properties of the temporary blocking agents should be known in order to choose the correct one for a specific well to be treated.

6. Specific well characteristics to be considered in choosing the correct temporary blocking agent are:
   a. Type of formation
   b. Openings to be blocked
   c. Temperature and pressure
   d. Local experience
   e. Type of completion

ACKNOWLEDGMENT

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DISCUSSION

C. L. Kistner (The Ohio Oil Co., Los Angeles, Calif.) (written) Mr. White has presented a clear, detailed explanation of temporary blocking agents and their application.

The paper points out again the value of forethought to determine the results desired, analysis of the well and formation conditions, and selection of the proper combination of materials and methods to achieve those results. Information is presented which aids in this selection.

Because of the high degree of permeability variation in most California “dirty” sands, the commenter is partial to the theory of deep-sealing agents rather than well-bore bridges. It is believed that well-bore bridges cannot control a fracture extending into the formation and that this may permit communication of the fracture into more permeable portions of the formation.

The author has confined his well-written paper to temporary blocking agents. Lest the impression be gained that this is "The Method" for fracturing, it should be pointed out that other very successful methods and materials must also be considered.

Local experience is mentioned as one of the most valuable aids in choosing a suitable blocking agent. Unfortunately, California experience has not led to a generally applicable fracturing technique. This paper may be of some aid to California operators in developing a practical method that will be successful here.

R. M. Brazier (Sunray Mid-Continent Oil Co., Newhall, Calif.) (written) Mr. White is to be complimented for his interesting review and resume of temporary blocking agents as used in fracturing and acidizing operations.

Because the results obtained from fracturing or acidizing in California generally haven't been nearly as effective as those in the Mid-Continent and Rocky Mountain areas, this paper may well serve as a stimulus to intrepid operators for a renewed attack with a different approach.

Because of this, it might be well if Mr. White would review for us the use and effectiveness of these various temporary blocking agents and techniques as experienced in California by his company, as compared with treatments where temporary blocking techniques were not used.

An interesting point is the statement by the author that "Temporary blocking is usually for a very short
period of time with no permanent reduction in permeability." It is my understanding that laboratory studies using oil-sand cores have generally shown substantial reductions in back-flow permeabilities to oil after being exposed to fluids containing substances foreign to the native formation fluids. Thus it would seem that any of the agents used for the temporary blocking of a producing-sand interval might cause some permanent damage, especially when deep-sealing agents are used.

Regarding the heavy-metal soap-kerosene gel, the following questions arise:

1. Is the acid-soluble weighting material a necessary ingredient for making a satisfactory gel, or does it primarily facilitate fracturing by allowing lower surface-pump pressures?
2. Is the acid-soluble weighting material normally produced back with the gel-broken fluids or is a subsequent acid treatment advisable?
3. What is the range of densities which can be readily attained?
4. Why is it not advisable to use this gel at bottom-hole temperatures above 220 F?

Regarding the perforation-sealing balls:

1. What are the critical bottom-hole temperatures above which nylon and rubber-covered nylon balls should not be used?
2. Where high surface pressures have been encountered during a treatment with rubber-covered nylon balls, how much bottom-hole pressure differential has been required to back flow most of the balls to the well bore?
3. What is the average percentage of balls returned to the well bore after high-pressure treatments?
4. Does "catch" efficiency refer to the percentage of balls temporarily plugging a perforation, and if so, what "catch" efficiencies are generally experienced?

In conclusion, it has been postulated by some operators that interbedded sands or stringers of relatively high permeability, especially in thick beds or intervals, may have been taking the majority of all fluids injected and might account for the poor showing of fracturing in California. Perhaps, as pointed out by Mr. White, deep-sealing hydrocarbon gels would give increased results, provided that permeability reductions were not too severe.

Mr. White (written) I wish to thank Mr. Brazier for his very pertinent comments.

As Mr. Brazier pointed out, acidizing and fracturing have not been so successful in California as in the Mid-Continent and Rocky Mountain areas, therefore, comparatively few treatments have been done. Proper evaluation has been impossible because of the limited number of treatments in California.

Many authorities believe, and have made calculations to show that when a fracture is created or extended, the matrix permeability can be reduced as much as 95 percent with no subsequent reduction in production. This of course is not true in the case where the fluid enters the well bore only from the walls of the well as may be the case in many areas in California. Neither does it mean that formation-damage tests should ever be neglected when considering any treating fluid. Formation-damage tests have been conducted on a core sample from the 7th zone of the Newhall-Potrero Field. The tests were conducted at 150 F using a 112 centipoise oil (Standard Oil Company's No 9 white oil). Permeability of the sample at water saturation was determined at 50 psi. The core was treated with metallic soap-hydrocarbon gel. The permeability of the core was again determined at 1, 10, 50, and 100 psi. Maximum permeability before blocking was 21.7 millidarcys. Average permeabilities after blocking were 11.6, 21.1, 24.1, and 23.6 millidarcys, respectively.

In reply to Mr. Brazier's questions concerning the heavy-metal soap-kerosene gel:

1. The acid-soluble weighting material is not a necessary ingredient for making a satisfactory gel. It reduces the fluid loss of the thin gel, and of course increases the density.
2. The weighting material is usually produced back with the fluid or settles to the bottom of the bore hole, so that subsequent acid treatment is rarely required.
3. The range of densities which can be readily obtained are from 6.82 to 9.26 lb per gal (51.0 to 69.3 lb per cu ft).
4. It is not advisable to use this gel at a bottom-hole temperature greater than 220 F because a blocking viscosity can be retained for only a short time at temperatures above 220 F. Work is now being done to extend the temperature limits of this gel.

Regarding the perforation-sealing balls:

1. The nylon balls should not be used in 15-percent hydrochloric acid at temperatures above 150 F. Both nylon and rubber-covered nylon balls can be used in oil to 300 F.
2. This is not known. However, the experience in California has been 100 percent recovery of balls after treatments with pressures as high as 7,500 psi.
3. In testing, "catch" efficiency refers to the number of times a ball will seal a perforation in a given number of opportunities. I would say that in application, at high injection rates, "catch" efficiency has been greater than 80 percent.