Introduction

The leakoff characteristics of a fracturing fluid are an important parameter in the design and execution of a hydraulic fracturing treatment. Reducing the amount of fracturing fluid that leaks off into the formation during a treatment will increase the fracturing fluid volume that is available to maintain or propagate the fracture.

As fluid leaks from the fracture into the formation, a deposit of fluid-loss additive and polymer builds up at the fracture face. This deposit acts as a barrier to fluid loss and is commonly referred to as the gel filter cake.

In general, fluid-loss behavior can be divided into two distinct stages.

1. The first stage is the spurt-loss period, where the fluid has not yet built up a complete filter cake on the rock face. The spurt volume \( V_{spt} \) is a measure of how much leakoff is necessary before a competent filter cake can be established across the rock surface. In general, studies show that as the size of the pore throats or channels in the formation rock increases, so does the spurt loss. Therefore, formations that have either high permeability or natural fractures exhibit very high fluid loss.
2. The second stage occurs after the filter cake has built up. The fluid loss during this stage is usually controlled by the resistance of the filter cake, i.e. $C_w$. An example of the leakoff of a typical crosslinked fracturing fluid is shown in Figure 1.

**Figure 1: Fluid Loss of a Crosslinked Gel Fracturing Fluid**

![Graph showing fluid loss over time for different permeabilities](attachment:image.png)

The leakoff character of a fluid will change depending on the nature of the formation that is being stimulated. If the permeability is less than 1 md, the fluid loss is controlled by fluid leakoff through the filter cake since there is very little spurt loss. As the permeability increases, the spurt-loss volume will account for a greater fraction of the total fluid-loss volume. Generally, when the formation permeability is greater than 20 MD, the spurt loss becomes the dominant contributor to the total fluid loss.

**Fluid-Loss Additives: Types and Uses**

Fluid-loss additives are commonly used in hydraulic fracturing to reduce the rate of fracturing fluid leakoff. By increasing fracturing fluid efficiency, fluid-loss additives help reduce the overall cost of the fracturing fluid system. Most fluid-loss additives work by either reducing the spurt volume, i.e. accelerating filter-cake buildup, or by reducing $C_w$ (increasing filter-cake resistance). Figure 2 shows the effect of adding silica flour to the crosslinked fluid shown in Figure 1. This additive reduced the spurt volume and the $C_w$ coefficient. The total fluid loss of the 50-MD core was reduced from 3 mL/cm² to 1.75...
ml/cm².

Figure 2: Fluid Loss of a Crosslinked Gel Fracturing Fluid with Silica Flour Fluid-Loss Additive

The effectiveness of an additive depends on the formation type, the size distribution of the additive, and its mechanical strength. Studies show that some fluid-loss additives can be more effective when used in crosslinked gels than in linear gels because crosslinked gels have higher viscosity and greater filter cake toughness. Fluid-loss additives are usually not necessary if the permeability is less than 0.01 Md.

Halliburton has developed a wide range of fluid-loss additives that are effective in a variety of operating conditions. In general, these additives can be broken down into four classifications:

- Liquid hydrocarbon additives
- Oil-soluble additives
- Water-soluble (degradable) additives
- Inert additives

**Liquid Hydrocarbon Additives**

Liquid hydrocarbon additives are usually dispersed into the aqueous fracturing fluid,
typically at concentrations of 1 to 5% by volume. These additives do not have any significant effect on the spurt loss but work primarily by reducing the $C_w$ coefficient. Experimental evidence indicates that hydrocarbon additives do not significantly benefit fluid-loss control when used with a linear gel. These additives should only be used in crosslinked fluid systems. They are most effective in formations where the permeability is less than 10 Md. Hydrocarbon additives are not expected to be very effective beyond 10 MD because of their inability to reduce spurt loss.

In formations where the permeability is less than 2 MD, liquid hydrocarbon additives are the most effective additives for reducing fluid loss. For example, fluid-loss experiments indicate that in crosslinked gel, 0.7% diesel was more effective than 40-lb silica flour/Mgal as a fluid-loss control additive. These test results suggest that the 0.5 to 0.7% diesel present in liquid gel concentrates (LGCs) will help provide nearly 75% of the benefit obtained from the use of higher diesel concentrations. Note, however, that proper dispersion of the diesel is critical for the diesel to act as an effective fluid-loss control agent.

**Oil-Soluble Additives**

Oil-soluble additives are particulates that are soluble in liquid hydrocarbons and should only be used in oil wells or wells with significant condensate production. These additives provide very good fluid-loss control over a wide range of permeabilities (0.1 MD to 2,000 MD). Halliburton's Matriseal O oil-soluble resin is effective at reservoir temperatures as high as 250°F.

Since these additives are soluble in oil, they provide better cleanup and less damage to the formation or proppant bed conductivity. Oil-soluble additives are most effective in reducing the spurt-loss volumes, but they also reduce $C_w$. They are also the most expensive of the four additive types.

**Water-Soluble or Degradable Additives**

Water-soluble or degradable fluid-loss additives can be used in any formation that has some water production. Since they are degradable, these additives provide better cleanup and less damage to proppant bed conductivity. They may, however, have some temperature limitations that restrict their use. Table 3 shows the working temperature range for some of the additives. Water-soluble fluid-loss additives are usually more expensive than inert or liquid hydrocarbon additives.

**Table 3: Recommended Temperature Application Ranges for Fluid-Loss Additives.**
WLC-4 and WLC-5 are two Halliburton starch-based fluid-loss additives. These additives are equally effective in reducing spurt and $C_w$. Experimental studies indicate that starch additives are most effective in formations where the permeability is less than 2 Md. In higher-permeability formations, starches, because of their limited mechanical strength, extrude into the rock and do not offer effective fluid-loss control. The use of these additives in crosslinked fluids extends their effective permeability range.

Halliburton's WLC-6 works well with high-pH fluids such as borate crosslinked gels, but it can also be used in lower pH systems. It is easier to disperse than WLC-4 or WLC-5. WLC-6 tends to slightly affect the pH of the fluid.

**Inert Additives**

These additives are the most commonly used and most versatile of all fluid-loss additive types. They can be used in conjunction with gelling agents in oil-, acid-, or water-based fracturing fluids and are effective over the entire permeability range (0.1 to 2,000 MD) for which they have been tested. These additives are most effective in reducing spurt loss, but they also help reduce the $C_w$ coefficient. Since these additives do not dissolve or degrade with time, they can cause some formation and/or proppant bed conductivity damage. They are the least expensive of all additive types. The use of inert additives in formations where the permeability is greater than 20 MD requires careful engineering judgment because of concerns about formation damage and proppant bed damage. In

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**Table 3—Recommended Temperature Application Ranges for Fluid-Loss Additives**

<table>
<thead>
<tr>
<th>Additive</th>
<th>Min. Temp. (°F)</th>
<th>Max. Temp. (°F)</th>
<th>Cost Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAC-9</td>
<td>50</td>
<td>500</td>
<td>0.1</td>
</tr>
<tr>
<td>SSA-2</td>
<td>50</td>
<td>500</td>
<td>0.2</td>
</tr>
<tr>
<td>Adomite Aqua</td>
<td>50</td>
<td>350</td>
<td>3.1</td>
</tr>
<tr>
<td>WLC-4</td>
<td>150</td>
<td>350</td>
<td>4.2</td>
</tr>
<tr>
<td>WLC-5</td>
<td>50</td>
<td>350</td>
<td>3.5</td>
</tr>
<tr>
<td>WLC-6</td>
<td>50</td>
<td>150</td>
<td>3.2</td>
</tr>
<tr>
<td>Adomite Regain</td>
<td>50</td>
<td>350</td>
<td>3.4</td>
</tr>
<tr>
<td>Matrisel O</td>
<td>50</td>
<td>250</td>
<td>7.4</td>
</tr>
<tr>
<td>QSR-100</td>
<td>50</td>
<td>250</td>
<td>5.3</td>
</tr>
<tr>
<td>FLD-ID</td>
<td>50</td>
<td>400</td>
<td>*</td>
</tr>
<tr>
<td>FLD-Ix</td>
<td>50</td>
<td>400</td>
<td>*</td>
</tr>
</tbody>
</table>

* 1.17 x price of diesel/gal + 1.3

To find information concerning other additives, see the *Halliburton Fracturing Services Manual* or contact the Duncan Technology Center.
these treatments, high proppant conductivity and low formation damage are essential for good production results. As a rule, inert additives should not be used in FracPac treatments. The higher fluid loss caused by absence of fluid-loss additive is an acceptable tradeoff for preventing damage.

**Using a Combination of Fluid-Loss Additives**

In some situations, a combination of hydrocarbon and inert (or water-soluble) particulates may be used to provide good fluid-loss control. The combination will usually result in reduced spurt volumes and lower $C_w$ numbers. The particulate additive helps reduce the spurt volume, and the hydrocarbon additive reduces the $C_w$. In most cases, experiments show that the use of a combination of these two fluid-loss additives provides better fluid-loss control than using either one alone.

The relative benefit of combining fluid-loss additives depends heavily on the permeability of the formation. Most reservoirs tend to have a wide distribution of permeability. For example, a reservoir with an average permeability of 1 MD will typically have permeability streaks of 3 to 7 Md. These high-permeability streaks, while a relatively small component of the reservoir, will result in higher spurt losses. As a result, the inert particulate additives become more important as fluid-loss control agents. However, as discussed in an earlier section, do not use inert particulates in high-permeability reservoirs because of potential for formation and proppant bed damage. In low-permeability formations, the major additive controlling fluid loss will be the hydrocarbon additive. Therefore, adding particulate additives such as WAC-9 or WLC-4 for permeabilities < 1 MD, does not significantly improve fluid-loss control unless high-permeability streaks or natural fractures exist within the formation.

**Fluid-Loss Additive Selection**

Selection of a fluid-loss additive is a judgment based on total cost, expected fluid-loss control, formation/proppant bed damage concerns, expected production increase, and field experience. The following selection guidelines and charts are designed to aid you in this process and will be periodically revised. If this information is inconsistent with field experience in your area, please inform your PSL representative. Your experiences will be used to help create revisions of these guidelines.

1. Determine the nature of the formation. The most important parameters to determine are the permeability of the formation and the presence of any natural fractures. The presence of natural fractures can have a severe impact on the fluid loss since they can open up even further during the treatment.

2. Decide which mechanism, i.e., spurt volume or $C_w$, is the major factor for the fluid
loss. For example, the presence of high-permeability "thief zones" and/or natural fractures can lead to very high spurt volumes. Therefore, an additive that reduces the spurt volume will result in better fluid-loss control than one that only affects the $C_w$ coefficient. In low-permeability formations, the reverse is true. A combination of fluid-loss additives may be appropriate if the objective is to reduce both the spurt volume and the $C_w$ coefficient.

3. Once you have determined the dominant fluid-loss mechanism, select the appropriate fluid-loss additive or additives by using Tables 1 through 3. These tables show the additives that are effective within each selected permeability range. Table 1 shows the additive selection chart for linear gel fracturing fluids, Table 2 shows the corresponding chart for crosslinked fracturing fluid systems, and Table 3 provides recommended temperature application ranges for a number of additives.

Table 1: Fluid-Loss Additive Selection, Linear Gels

<table>
<thead>
<tr>
<th>Permeability</th>
<th>0.01 ≤ 2 md</th>
<th>2 to 10 md</th>
<th>10 to 100 md</th>
<th>≥100 md* or Natural Fractures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid-Loss Additive</td>
<td>WLC-4 (WS)</td>
<td>WAC-9 (l)</td>
<td>WLC-6 (WS)</td>
<td>WLC-9 (l)</td>
</tr>
<tr>
<td>Adomite Regain (WS)</td>
<td>(OS)</td>
<td>Adomite Aqua (l)</td>
<td>(OS)</td>
<td>SSA-2 + WAC-9 (l)</td>
</tr>
<tr>
<td>WLC-6 (WS)</td>
<td>(OS)</td>
<td>MATRISEAL O (OS)</td>
<td>(OS)</td>
<td>MATRISEAL O (OS)</td>
</tr>
<tr>
<td>Adomite Aqua (l)</td>
<td>(OS)</td>
<td>(OS)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
<tr>
<td>WAC-9 (l)</td>
<td>(OS)</td>
<td>(OS)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
<tr>
<td>MATRISEAL O (OS)</td>
<td>(OS)</td>
<td>(OS)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
</tbody>
</table>

Table 2: Fluid-Loss Additive Selection, Crosslinked Gels

<table>
<thead>
<tr>
<th>Permeability</th>
<th>0.01 ≤ 2 md</th>
<th>2 to 10 md</th>
<th>10 to 100 md</th>
<th>≥100 md* or Natural Fractures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid-Loss Additive</td>
<td>FLD-ID (HC)</td>
<td>WLC-4 (WS)</td>
<td>WLC-6 (WS)</td>
<td>WAC-9 (l)</td>
</tr>
<tr>
<td>FLD-DX (HC)</td>
<td>(OS)</td>
<td>Adomite Regain (WS)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
<tr>
<td>WLC-4 (WS)</td>
<td>(OS)</td>
<td>WLC-5 (WS)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
<tr>
<td>WLC-5 (WS)</td>
<td>(OS)</td>
<td>Adomite Regain (WS)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
<tr>
<td>Adomite Aqua (l)</td>
<td>(OS)</td>
<td>WAC-9 (l)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
<tr>
<td>WLC-6 (WS)</td>
<td>(OS)</td>
<td>Adomite Aqua (l)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
<tr>
<td>Adomite Aqua (l)</td>
<td>(OS)</td>
<td>MATRISEAL O (OS)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
<tr>
<td>MATRISEAL O (OS)</td>
<td>(OS)</td>
<td>FLD-ID (HC)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
<tr>
<td>WAC-9 (l)</td>
<td>(OS)</td>
<td>FLD-DX (HC)</td>
<td>(OS)</td>
<td>(OS)</td>
</tr>
</tbody>
</table>

Legend

(HC) Hydrocarbon Additive

(OS) Oil-Soluble Additive
(WS) Water-soluble Additive

(I) Inert Additive

*Inert fluid-loss additives should be used with care in high-permeability formations because of possible formation and proppant conductivity damage.

4. Select the additive from the list of appropriate additives based on the expected improvement in fluid-loss control, the expected damage to the formation and/or proppant bed conductivity, and field experience with the particular formation. The appropriate concentration of the fluid-loss additive can be decided based on the effect of the fluid-loss additive concentration on the spurt and C_w coefficient. This data is available in the Halliburton Fracturing Services manual and can be used to determine the correct concentration.

Selecting Additive Concentration

After you have selected a fluid-loss additive, the next step is to determine the best additive concentration to use for the treatment. This decision can be made based on the additive's effect on the spurt and C_w coefficient. This section contains information on recommended concentrations for some of the common additive types. Information on these and other additives is available in the Halliburton Fracturing Services manual, which can be used to determine the correct concentration.

Liquid Hydrocarbon Additives

Experimental data shows that diesel in crosslinked gel is very effective in controlling fluid loss in formations where the permeability is less than 10 Md. The overall fluid loss was reduced by approximately 50% as compared to fluid loss for the gel without any additive. On 1-MD permeability cores, the C_w coefficient was reduced from 0.0045 to 0.0017 ft/min 0.5 as the diesel concentration was increased from 0 to 10%. The greatest reduction in C_w occurs by the dispersion of 0.5% diesel. This concentration provides almost 80% of the maximum benefit that can be obtained through the use of higher diesel concentrations. The fluid loss declines further as the diesel concentration increases. However, the change in the fluid loss is not as significant. Figure 3 shows a plot of the C_w coefficient on 1-MD rock for various diesel concentrations. The same conclusions will apply for other hydrocarbon fluid-loss additives.

Figure 3: C_w Coefficient for 1-MD Rock vs. Diesel Content
As the permeability increases beyond 10 MD, the effect of the spurt loss becomes more important. Hydrocarbon additives do not help reduce the spurt loss. Figure 4 shows a plot of the spurt loss for two different permeability rocks at various diesel concentrations. Diesel does very little to affect spurt loss. However, it does help reduce the filter cake coefficient $C_w$.

**Figure 4: Spurt Loss vs. Diesel Concentration**

Figure 5 shows the plot for $C_w$ on rocks with permeabilities over 1 Md.
Oil-Soluble Additives

Oil-soluble additives can be used at concentrations between 20 and 50 lb/Mgal; a recommended concentration is 40 lb/Mgal. Oil-soluble additives should not be used at temperatures greater than 250°F.

Water-soluble Additives

Water-soluble additives work by reducing the spurt and $C_w$. Typically used in concentrations ranging from 20 to 50 lb/Mgal, the best concentration of water-soluble additive depends on the formation permeability and the base polymer concentration.

Inert Additives

Adding inert additives improves fluid-loss control principally by reducing the spurt loss. Inert additives also reduce the filter cake coefficient $C_w$. Table 4 shows the reduction of the $C_w$ coefficient for a crosslinked fluid at 180°F with WAC-9 on low-permeability (< 1 MD) rock. The fluid loss decreases by 12.5% as the WAC-9 concentration is increased from 0 to 10 lb/Mgal. When the WAC-9 concentration is increased to 40 lb/Mgal, the fluid loss decreases by an additional 10%. However, when the WAC-9 concentration is increased to 100 lb/Mgal, the beneficial effects become less significant. Therefore, using
WAC-9 at concentrations over 40 lb/Mgal may not be economical.

Table 4: $C_w$ Coefficient at Various WAC-9 Concentrations for <1 MD rock (Crosslinked Gel, 180°F)

<table>
<thead>
<tr>
<th>WAC-9 Concentration (lb/Mgal)</th>
<th>$C_w$ (ft/min$^{0.5}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0045</td>
</tr>
<tr>
<td>10</td>
<td>0.0040</td>
</tr>
<tr>
<td>40</td>
<td>0.0036</td>
</tr>
<tr>
<td>100</td>
<td>0.0034</td>
</tr>
</tbody>
</table>

As the permeability increases, the contribution of spurt loss to the total fluid loss becomes more important. WAC-9 and other particulate additives are effective agents for reducing spurt loss. Figure 6 shows the effect of WAC-9 on spurt loss. Increasing the WAC-9 concentration helps reduce spurt loss. However, there are diminishing returns in terms of reduced spurt volume as WAC-9 concentrations are increased. Again, the 40 lb/Mgal concentration appears to be the best WAC-9 concentration.

Figure 6: Spurt Loss vs. WAC-9 Concentration

Combination of Fluid-Loss Additives

In some situations, using a combination of hydrocarbon and inert (or water-soluble) additives results in reduced spurt volumes and lower $C_w$ numbers. For permeabilities
ranging from 3 to 10 MD, a combination of 5% hydrocarbon fluid-loss additive with 40-lb WAC-9/Mgal provides good fluid-loss control. The same formulation works at higher permeabilities as well. However, as discussed in an earlier section, inert particulates should not be used in high-permeability reservoirs because of concerns about formation and proppant bed damage.

**Example 1**

**Well Conditions**

- A naturally fractured oil formation occurs at a depth of 10,000 ft. The bottomhole temperature is 240°F.
- Core analysis and other information indicate that the matrix permeability is 3 Md.
- Natural fractures are present.
- A crosslinked gel will be used for the fracturing fluid.

**Fluid-Loss Additive Selection**

Since the natural fractures would account for the bulk of the leakoff, the selection of the fluid-loss additive should be based on reducing leakoff to the fractures. The large size of the natural fractures would require large particle sizes to effectively bridge them. Furthermore, the leakoff would be dominated by the spurt loss rather than the fluid loss after the filter cake has been built up. Therefore, the fluid-loss additive should be selected to minimize the spurt volume. Table 2 identifies that using the mixture of OSR 100 + MATRISEAL® O (oil-soluble) or SSA-2+WAC-9 (inert) is appropriate.

Please note that oil-soluble additives are the most expensive of the additive types. When treatment cost is critical, use inert SSA-2 + WAC-9, and run it at 20 to 40 lb/Mgal, depending on local experience.

**Example 2**

**Well Conditions**

- A low-permeability gas formation occurs at a depth of 12,500 ft.
- The bottomhole temperature is 285°F.
- The average formation permeability is 0.1 Md.
- A crosslinked gel will be used for the fracturing fluid.

**Fluid-Loss Additive Selection**

In a low-permeability system, spurt volumes are very small. Therefore, the fluid-loss additive selection should be made with the objective of reducing the $C_w$ coefficient, which can be accomplished by the use of a hydrocarbon fluid-loss additive. At higher
temperatures, the volatility of diesel is not a factor. Therefore, FLD-ID should be used as
the fluid-loss additive.