CHAPTER 4 Field Applications and Brine Maintenance

The information in this chapter addresses needs and decisions that often arise in the field after the completion fluid has been transported to the location.

This chapter will cover:

1. General Density Equations
2. Brine Volume Calculations
3. Weight Up of Single Salt Brine with Dry Chemicals
4. Cutback Calculations
5. Mixing Viscosified Pills
6. Spotting Balanced Pills
7. Slug Calculations

General Density Equations

From time to time, it will be necessary to adjust the density of a clear brine completion fluid. A completion fluid may become diluted by rain, seawater, or by water from the producing formation. Additionally, bottomhole pressure conditions may demand that a fluid weight up be performed to maintain well control. On the other hand, cutting back a fluid's density may also be required to reduce invasion of wellbore fluids into the formation.

The most basic form of the density equation is given as mass per unit volume, ordinarily in units of pounds per gallon (lb/gal).

$$density = \frac{mass}{volume}$$

The equation can be rearranged to solve for weight, as shown here.

$$density * volume = mass$$

All density adjustment calculations are made using expanded forms of the preceding equations. Equation 7 is used for weight up or cutback calculations. It is the most general form used in most oilfield density adjustment calculations. Equation 8 states that the final volume is the combination of the starting volume and the added volume. A small error results from the complex interaction of water and the brine chemicals. These equations are good approximations, but they will require a field check for final density. Virtually all density calculations—weight up, cutback, or volume—are done using some variation of Equation 7 and/or Equation 8.

EQUATION 7.

$$d_f = \frac{(d_1 * v_1) + (d_2 * v_2)}{v_1 + v_2}$$

d_f = density of final target fluid, lb/gal

d_1 = density of starting fluid, lb/gal

v_1 = volume of starting fluid, bbl

d_2 = density of added fluid, lb/gal

v_2 = volume of added fluid, bbl

EQUATION 8.

$$v_f = v_1 + v_2$$

v_f = volume of final target fluid, bbl

v_1 = volume of starting fluid, bbl

v_2 = volume of added fluid, bbl

The next group of equations deals with density adjustment, rearranging the terms in Equation 7 and Equation 8 to allow you to find the quantities you will need.

Mixing Two Known Fluids—Unknown Final Density

The least complicated situation involves determining the final density when mixing together two fluids of known density and known volume. The density is determined using Equation 7 as it is written above. Also in this case, the final volume (v_f) is the sum of the volume of the two fluids straight out of Equation 8.

EXAMPLE A. Determining Final Density, d_f, When d_1, v_1, d_2, and v_2 are Known

Find:

v_f, final volume

d_f, final density

Given:

v_1 = 650 bbl

d_1 = 15.6 lb/gal

v_2 = 150 bbl

d_2 = 14.2 lb/gal

$$v_f = v_1 + v_2$$

$$v_f = 650 \text{ bbl} + 150 \text{ bbl}$$

$$d_f = \frac{(d_1 * v_1) + (d_2 * v_2)}{v_f}$$

$$d_f = \frac{(15.6 \text{ lb/gal} * 650 \text{ bbl}) + (14.2 \text{ lb/gal} * 150 \text{ bbl})}{800 \text{ bbl}}$$

Answers:

v_f = 800 bbl

d_f = 15.3 lb/gal

Mixing Two Known Fluids—Known Final Density

The following situation arises frequently and may even be the most common volume density calculation. You know the densities of the two starting fluids (d_1 and d_2) and the desired final density (d_f). What you want to know are the volumes of the two fluids (v_1 and v_2) that you need to mix to get one barrel of final density (d_f) fluid. Start by using Equation 9 to find the volume of fluid 1 (v_1).

EQUATION 9.

$$v_1 = \frac{(d_f - d_2)}{(d_1 - d_2)}$$

v_1 = volume of fluid 1, bbl

d_f = density of final fluid, lb/gal

d_1 = density of fluid 1, lb/gal

d_2 = density of fluid 2, lb/gal

Then, set the final volume (v_f) to 1.00 and subtract the calculated volume (v_1) to get the volume of fluid 2 (v_2) using Equation 8.

EXAMPLE B. Finding Volume Proportions of Two Known Fluids Needed to Make One Barrel of Known Density Fluid

Find:

v_1, volume

v_2, volume

Given:

v_f = 1.00 bbl

d_f = 15.0 lb/gal

d_1 = 16.5 lb/gal

d_2 = 14.2 lb/gal

$$v_1 = \frac{(d_f - d_2)}{(d_1 - d_2)}$$

$$v_1 = \frac{(15.0 \text{ lb/gal} - 14.2 \text{ lb/gal})}{(16.5 \text{ lb/gal} - 14.2 \text{ lb/gal})}$$

$$v_2 = v_f - v_1$$

$$v_2 = 1.00 \text{ bbl} - 0.348 \text{ bbl}$$

Answers:

v_1 = 0.348 bbl

v_2 = 0.652 bbl

Kill Weight Fluids

Completion fluid density is specifically designed to control well pressure; this being the case, most brines are kill weight fluids. Determining the appropriate density has been outlined in some detail in the section "Fluid Categories" on page 10. In some instances, shut in bottomhole pressure (SIBP) may be substituted for anticipated bottomhole pressure (BHP), and any overbalance or underbalance will be included; however, the calculation process is essentially the same, using Equation 1 and Equation 2 on page 12.

EXAMPLE C. Kill Weight Fluid Density

Find:

grad, pressure gradient

d, kill weight fluid density

Given:

BHP (or SIBP) = 9,500 psi

overbalance = 200 psi

TVD = 15,000 ft

$$grad = \frac{BHP + overbalance}{TVD}$$

$$grad = \frac{9500\ psi + 200\ psi}{15000\ ft}$$

$$d = \frac{grad}{0.052}$$

$$d = \frac{0.647\ psi/ft}{0.052}$$

Answers:

grad = 0.647 psi/ft

d = 12.4 lb/gal

Typically, when using a completion fluid, the task will be to weight a fluid up to a higher density.

Weight Up of Working Fluid with Spike Fluid

The following calculations are applicable when the density of the circulating fluid needs to be increased. There are two cases. The first case, shown in Example D, uses Equation 7 to determine the density that can be achieved by adding a known amount of spike fluid to a known circulating volume. In this case, the final volume (v_f) will increase. This case is identical to Example B of mixing two fluids of known density and volume. The final volume (v_f) is the combined volume of initial fluid (v_1) and spike fluid (v_2).

EXAMPLE D. Weight Up with Spike Fluid

Find:

v_f, final volume

d_f, final density

Given:

v_1 = 650 bbl

d_1 = 15.6 lb/gal

v_2 = 150 bbl

d_2 = 19.2 lb/gal

$$v_f = v_1 + v_2$$

$$v_f = 650 + 150$$

$$d_f = \frac{(d_1 * v_1) + (d_2 * v_2)}{v_f}$$

$$d_f = \frac{(15.6 \text{ lb/gal} * 650 \text{ bbl}) + (19.2 \text{ lb/gal} * 150 \text{ bbl})}{800 \text{ bbl}}$$

Answers:

v_f = 800 bbl

d_f = 16.28 lb/gal

The second case, shown in Example E, is used when there is a volume limitation, meaning that the final volume (v_f) is limited to the available holding capacity of the hole and surface equipment.

In this example, the volume is limited to the hole and surface equipment capacity (v_f). The task is to find the maximum density that can be achieved with an initial starting fluid density (d_1) using a fixed amount (v_2) of spike fluid of a known density (d_2).

EXAMPLE E. Weight Up Using Spike Fluid with Volume Limitation

Find:

v_1, volume

d_f, final density

Given:

v_f = 1,200 bbl

d_1 = 12.8 lb/gal

v_2 = 250 bbl

d_2 = 14.2 lb/gal

$$v_1 = v_f - v_2$$

$$v_1 = 1200\ bbl - 250\ bbl$$

$$d_f = \frac{(d_1 * v_1) + (d_2 * v_2)}{v_f}$$

$$d_f = \frac{(12.8\ lb/gal * 950\ bbl) + (14.2\ lb/gal * 250\ bbl)}{1200\ bbl}$$

Answers:

v_1 = 950 bbl

d_f = 13.1 lb/gal

Surface Density Correction

As a fluid circulates through a well, it experiences changes in temperature, and expands and contracts in relation to this heating and cooling. Because of this expansion and contraction, the density of the fluid may appear to be off. Fluid engineers will use one of the correction factors from Table 9 and apply Equation 10 on page 66 to account for these temperature changes and determine the fluid's density at 60°F.

TABLE 9. Surface Density Correction Factors

Fluid Density	Correction Factor
8.4 – 9.0 lb/gal	0.0002
9.1 – 11.0 lb/gal	0.0003
11.1 – 14.5 lb/gal	0.0004
14.6 – 16.0 lb/gal	0.0005
16.1 – 18.0 lb/gal	0.0006
18.1 – 19.2 lb/gal	0.0007

EQUATION 10.

$$d_c = (\Delta T * CF + HR) * d_w$$

d_c = fluid density, corrected to 60°F, lb/gal
ΔT = sample temperature - 60°F, °F
CF = correction factor, (lb/gal)/°F
HR = hydrometer reading at sample temperature
d_w = density of fresh water, 8.34 lb/gal

The example below illustrates a surface density correction for a fluid with an initial density of 10.0 lb/gal.

EXAMPLE F. Surface Density Correction

Find:

ΔT, difference between sample temperature and 60°F

d_c, corrected density

Given:

C_T = 100°F

CF = 0.0003

HR = 1.187

d_w = 8.34 lb/gal

$$\Delta T = C_T - 60°F$$

$$\Delta T = 100°F - 60°F$$

$$d_c = (\Delta T * CF + HR) * d_w$$

$$d_c = (40°F * 0.0003 + 1.187) * 8.34 \text{ lb/gal}$$

Answers:

ΔT = 40°F

d_c = 9.99 lb/gal

Brine Volume Calculations

Maximum Volume of a Specific Density

You have a set amount of spike fluid and need to find the maximum volume (v_f) of a target density that can be mixed from a starting fluid. The first thing to do is to calculate the volume of starting fluid (v_1) that will be required to be mixed with the fixed volume of spike fluid (v_2) to get to the density you want (d_f).

EQUATION 11.

$$v_1 = v_2 * \left(\frac{d_2 - d_f}{d_f - d_1}\right)$$

d_f = density of final fluid, lb/gal
d_1 = density of fluid 1, lb/gal
v_1 = volume of fluid 1, bbl
d_2 = density of fluid 2, lb/gal
v_2 = volume of fluid 2, bbl

The final total volume (v_f) goes back to Equation 8 on page 60. You already know the spike volume (v_2) and have calculated the quantity of starting fluid needed (v_1), so the final volume (v_f) is the sum of the two.

$$v_f = v_1 + v_2$$

In Example G, the density of the starting fluid (d_1), the density of the spike fluid (d_2), and the final target density (d_f) are all known. In addition, the volume of spike fluid that is available (v_2) is known.

EXAMPLE G. Weight Up to Target Density with Spike Fluid

Find:

v_1, volume

v_f, final volume

Given:

d_f = 16.1 lb/gal of final fluid

d_1 = 15.8 lb/gal of starting fluid

v_2 = 100 bbl of spike fluid

d_2 = 19.2 lb/gal of spike fluid

$$v_1 = v_2 * \left(\frac{d_2 - d_f}{d_f - d_1}\right)$$

$$v_1 = 100\ bbl * \left(\frac{19.2\ lb/gal - 16.1\ lb/gal}{16.1\ lb/gal - 15.8\ lb/gal}\right)$$

$$v_f = v_1 + v_2$$

$$v_f = 1033\ bbl + 100\ bbl$$

Answers:

v_1 = 1,033 bbl

v_f = 1,133 bbl

Weight Up of Single Salt Brine with Dry Chemicals

When single salt brines become diluted with water, they can be reconstituted to their original composition by adding dry or crystalline chemicals to the diluted brine, provided sufficient mixing equipment is available. Reference information showing the weight percent contained at different densities (pct_f and pct_{dil}) can be found in the density and composition tables in Chapter 6 in the section titled, "Single Salt Fluid Composition and Blending Tables" on page 145.

EQUATION 12.

$$lb_{pure} = \frac{pct_f - pct_{dil}}{1 - pct_f} * d_{dil} * 42$$

lb_{pure} = weight of pure salt (100% basis) per barrel of original brine, lb/bbl

pct_f = percent of pure salt (100% basis) in original brine, wt fraction

pct_{dil} = percent of pure salt (100% basis) in diluted brine, wt fraction

d_{dil} = density of diluted fluid, lb/gal

Note: pct represents weight percent as decimal fraction (i.e., 25% = 0.25)

Whenever dealing with dry chemicals, it is important to make sure you know the purity or percentage of pure salt contained in the product with which you are working. One to five percent water and impurities are not uncommon in technical grade chemicals. To calculate total product, divide the pounds of 100% compound (lb_{pure}) in Equation 12 by the purity percentage to increase the total product added to the recipe as illustrated in Equation 13.

EQUATION 13.

$$lb_{product} = \frac{lb_{pure}}{purity}$$

$lb_{product}$ = total product added to the recipe, lb/bbl

lb_{pure} = weight of pure salt (100%), lb/bbl

purity = weight percent as decimal fraction (i.e., 97% purity = 0.97)

Make sure you know the purity or percentage of pure salt contained in the product with which you are working.

Weight Up Tables

For a quicker way to determine the amount of weight material required for a density increase of a single salt brine by as much as 0.6 lb/gal, weight up tables, similar to the following one (Table 10), are provided in Chapter 6. They are organized by fluid type and density in the section titled, “Single Salt Fluid Composition and Blending Tables” on page 145.

In Table 10, as well as in all of the weight up tables in Chapter 6, column one provides starting density and the succeeding columns provide information for the pounds of dry salt of stated purity (in this case 99%) required to achieve a density increase of 0.1 lb/gal to 0.6 lb/gal. There will be a volume increase using this method, which is discussed in the text below Equation 14.

Remember that using dry chemicals in a weight up can result in a substantial temperature increase. A bench scale pilot can give an indication of how hot the fluid is likely to become. Always add dry chemicals slowly.

TABLE 10. Sodium Chloride (NaCl) Weight Up Table (lb/bbl)

Weight Up Using 99% NaCl						
Starting Density	Weight Up Increments (0.1 lb/gal)					
lb/gal	0.1	0.2	0.3	0.4	0.5	0.6
8.4	4.92	11.91	17.96	24.06	31.33	37.58
8.5	6.98	13.01	19.10	26.36	32.59	38.89
8.6	5.99	12.03	19.23	25.42	31.67	39.15
8.7	6.01	13.18	19.34	25.56	33.00	40.57
8.8	7.13	13.26	19.44	26.86	34.39	42.04
8.9	6.08	12.22	19.58	27.05	34.64	41.11
9.0	6.11	13.43	20.86	28.42	34.86	42.63
9.1	7.28	14.68	22.20	28.61	36.34	44.20
9.2	7.34	14.80	21.15	28.83	36.63	44.56
9.3	7.40	13.70	21.32	29.05	36.92	44.92
9.4	6.25	13.80	21.48	29.28	37.22	45.29
9.5	7.51	15.15	22.91	30.81	38.84	
9.6	7.57	15.28	23.11	31.07		
9.7	7.64	15.40	23.30			
9.8	7.70	15.53				
9.9	7.77					

Dry Salt Weight Up Volume Increase

The weight up tables like Table 10 and those provided in Chapter 6 assume that you are starting with one barrel of brine and will be adding dry salt to increase the density.

EQUATION 14.

$$v_f = \frac{(d_1 * 42) + lb_{product}}{(d_f * 42)}$$

v_f = final volume, bbl

d_1 = density of fluid 1, lb/gal

$lb_{product}$ = weight of salt product per barrel required to weigh up to final fluid density, lb/bbl

d_f = density of final fluid, lb/gal

Suppose you want to increase the density of an 8.8 lb/gal (d_1) NaCl brine to 9.1 lb/gal (d_2), a 0.3 lb/gal increase. This would require 19.44 lb of 99% NaCl (from Table 10) per barrel of starting brine. Applying Equation 14 above, shows that the volume would increase to 1.018 bbl, or 1.8 bbl per 100 bbl of starting brine treated.

EXAMPLE H. Weight Up of Single Salt Working Fluid with Dry Salt

Find:

v_f, final volume

Given:

d_1 = 8.8 lb/gal

d_2 = 9.1 lb/gal

$lb_{product}$ = 19.44 lb/bbl

$$v_f = \frac{(d_1 * 42) + lb_{product}}{(d_2 * 42)}$$

$$v_f = \frac{(8.8 \text{ lb/gal} * 42) + 19.44 \text{ lb/bbl}}{(9.1 \text{ lb/gal} * 42)}$$

Answer:

v_f = 1.018 bbl

Cutback Calculations

Cutback calculations can be done using two different approaches. The first is the volume density approach using Equation 8 and Equation 9 as shown in earlier examples. The second method, which is more accurate, uses Equation 15 below and the weight percentages of the dry salts in the starting fluid and final cutback fluid to calculate the fraction of a barrel of starting fluid that should be diluted with fresh water to get one full barrel at the target density (d_f). The weight percent values for each single salt fluid are provided in the density and composition tables in Chapter 6 in the section titled, "Single Salt Fluid Composition and Blending Tables" on page 145.

Cutback calculations are based on weight percent salt on a 100% basis dissolved in a fluid of a particular density. All the examples in this section assume the cutback is being done with fresh water. The goal is to determine the volume of starting fluid of density (d_1) that, when brought up to a final volume of one barrel, will give the correct final density (d_f). The formula for a cutback is given below in Equation 15.

EQUATION 15.

$$v_1 = \frac{(pct_{dil} * d_{dil})}{(pct_1 * d_1)}$$

v_1 = volume (as a fraction of a barrel) of fluid 1 (starting fluid), bbl
pct_{dil} = percent of dissolved salt in final fluid, wt fraction
d_{dil} = final diluted density, lb/gal
pct_1 = percent of dissolved salt in fluid 1 (starting fluid), wt fraction
d_1 = density of fluid 1 (starting fluid), lb/gal

Note: pct represents weight percent as a decimal fraction (i.e., 25% = 0.25)

Example I demonstrates the use of weight percentages and Equation 15 to calculate the volume of starting fluid needed to cut an 11.6 lb/gal calcium chloride fluid back to 10.9 lb/gal. The weight percent values used in the example below are taken from Table 39 on page 158.

Cutback Tables

A faster way to solve the cutback problem is by using a cutback table. Table 11 is the cutback table for calcium chloride; the density of the starting fluid (d_1) appears across the top and the final target density (d_f) is shown down the leftmost column. The values are in barrels of starting fluid that should be brought up to a final volume of one barrel by adding water. Cutback tables, such as the following one (Table 11), are provided in Chapter 6. They are organized by fluid type and density in the section titled, "Single Salt Fluid Composition and Blending Tables" on page 145.

EXAMPLE I. Cutting Back a Single Salt Fluid with Fresh Water

Find:

v_1, volume of fluid 1

Given:

pct_{dil} = 32.4% by weight $CaCl_2$

d_{dil} = 10.9 lb/gal $CaCl_2$

pct_1 = 39.8% by weight $CaCl_2$

d_1 = 11.6 lb/gal $CaCl_2$

$$v_1 = \frac{(pct_{dil} * d_{dil})}{(pct_1 * d_1)}$$

$$v_1 = \frac{(0.324 * 10.9 \text{ lb/gal})}{(0.398 * 11.6 \text{ lb/gal})}$$

Answer:

v_1 = 0.765 bbl

If, for instance, you are starting with 11.4 lb/gal (d_1) $CaCl_2$ and want to make 800 bbl of 10.2 lb/gal (d_{dil}) $CaCl_2$ fluid, you will need to follow the steps below.

To determine the quantity of 11.4 lb/gal fluid needed to make 800 barrels of 10.2 lb/gal fluid:

1. Locate the density of the starting fluid, in this case 11.4 lb/gal, along the top of Table 11.
2. Run down the 11.4 column until you intersect the 10.2 lb/gal row in the leftmost column.
3. Read the volume as the fraction of a barrel, 0.595 bbl. This means that for every one barrel of 10.2 lb/gal fluid, you will need to start with 0.595 bbl of 11.4 lb/gal fluid.
4. Multiply that number by the number of barrels you want in the end.
5. Add the amount of fresh water required to increase the fluid volume to the final desired volume.

To make 800 bbl of 10.2 lb/gal fluid, it will take 476 barrels of 11.4 lb/gal $CaCl_2$, diluted with fresh water up to a final volume of 800 bbl.

TABLE 11. Calcium Chloride ($CaCl_2$) Cutback Table (bbl/bbl)

Volume in Barrels of Starting Density (d_1) Fluid Needed for Cutback[1]										
Target Density	Starting Density (d_1) of Stock Fluid, lb/gal									
d_f	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6
8.4	0.026	0.025	0.024	0.023	0.022	0.021	0.020	0.020	0.019	0.018
8.5	0.052	0.050	0.048	0.046	0.044	0.043	0.041	0.040	0.038	0.037
8.6	0.090	0.086	0.083	0.079	0.076	0.074	0.071	0.068	0.066	0.064
8.7	0.136	0.130	0.125	0.120	0.116	0.112	0.107	0.104	0.100	0.097
8.8	0.162	0.155	0.149	0.143	0.138	0.133	0.127	0.123	0.119	0.115
8.9	0.207	0.199	0.191	0.184	0.177	0.170	0.163	0.158	0.153	0.147
9.0	0.256	0.246	0.236	0.227	0.219	0.211	0.202	0.195	0.189	0.182
9.1	0.301	0.289	0.277	0.267	0.257	0.247	0.237	0.229	0.222	0.214
9.2	0.344	0.330	0.317	0.305	0.293	0.282	0.271	0.262	0.254	0.244
9.3	0.388	0.372	0.357	0.343	0.330	0.318	0.305	0.295	0.286	0.275
9.4	0.432	0.414	0.398	0.383	0.368	0.355	0.340	0.329	0.318	0.307
9.5	0.474	0.455	0.437	0.420	0.404	0.389	0.373	0.361	0.350	0.337
9.6	0.518	0.497	0.477	0.459	0.441	0.425	0.407	0.394	0.382	0.368
9.7	0.562	0.539	0.518	0.498	0.479	0.461	0.442	0.428	0.414	0.399
9.8	0.607	0.582	0.559	0.537	0.517	0.498	0.477	0.462	0.447	0.431
9.9	0.649	0.623	0.598	0.575	0.553	0.533	0.511	0.494	0.479	0.461
10.0	0.693	0.664	0.638	0.613	0.590	0.568	0.545	0.527	0.510	0.492
10.1	0.737	0.707	0.679	0.652	0.628	0.605	0.580	0.561	0.543	0.523
10.2	0.781	0.750	0.720	0.692	0.666	0.641	0.615	0.595	0.576	0.555
10.3	0.824	0.790	0.759	0.730	0.702	0.676	0.648	0.627	0.607	0.585
10.4	0.867	0.832	0.799	0.768	0.739	0.711	0.682	0.660	0.639	0.616
10.5	0.911	0.873	0.839	0.806	0.776	0.747	0.717	0.693	0.671	0.647
10.6	0.955	0.916	0.880	0.846	0.814	0.784	0.751	0.727	0.704	0.678
10.7	1.000	0.959	0.921	0.886	0.852	0.821	0.787	0.761	0.737	0.710
10.8		1.000	0.960	0.923	0.888	0.856	0.820	0.794	0.768	0.741
10.9			1.000	0.961	0.925	0.891	0.854	0.826	0.800	0.771
11.0				1.000	0.962	0.927	0.889	0.860	0.832	0.802
11.1					1.000	0.963	0.923	0.893	0.865	0.834
11.2						1.000	0.959	0.928	0.898	0.866
11.3							1.000	0.968	0.937	0.903
11.4								1.000	0.968	0.933
11.5									1.000	0.964
11.6										1.000

[1]Calculated to make one barrel of final density fluid.

Mixing Viscosified Pills

Mixing a viscosified pill is a common task. The hydration and yield time for hydroxyethylcellulose (HEC) polymer varies in completion fluids that have different salt compositions and different densities. Factors which affect HEC hydration are time, temperature, shearing, fluid composition, pH, and HEC formulation.

Determining Product Type

Single Salt Fluids. TETRAVis can be used in any low density clear brine fluid when sufficient agitation, shearing, and time are available. TETRAVis L, an economical prehydrated polymer, is well suited for use in all single salt fluids. Its advantages are a shorter hydration time than that of a dry product, a decrease in the possibility of *fish eyes*, and greater ease of handling.

Multisalt Fluids. TETRAVis L Plus is the preferred viscosified pill for multisalt and higher density fluids. It is double the strength of TETRAVis L.

Brine Type

- All low density (<12.0 lb/gal) single salt fluids can be viscosified readily with TETRAVis or TETRAVis L. Excessive yield times can often be shortened by heating the fluid to a temperature higher than 130°F or by using TETRAVis L, as it is prehydrated.
- High density two salt fluids, such as NaCl/NaBr and $CaCl_2$/$CaBr_2$, may be viscosified with TETRAVis L or TETRAVis L Plus. Hydration times in these fluids will vary as a function of the salt and water concentrations of each particular fluid blend. Prior to the actual blending of any pill, a fluids specialist should run a pilot test.
- $ZnBr_2$/$CaBr_2$/$CaCl_2$ fluids can be viscosified with TETRAVis L Plus, as long as the $ZnBr_2$ concentration is greater than 28-30% by weight. When the $ZnBr_2$ concentration in the working fluid is less than this range, cut a 19.2 lb/gal $ZnBr_2$ spike fluid back with water to the desired density to make your pill. (This process is illustrated in Example J.)
- Based on standard composition, 19.2 lb/gal $ZnBr_2$ can be cut back with fresh water to a density of 12.1 lb/gal and still result in a fluid containing 30% $ZnBr_2$, which is sufficient to ensure viscosification.

Example J shows the calculation used to determine the fraction of both 19.2 lb/gal $ZnBr_2$ fluid and fresh water required to prepare 1 bbl of 15.9 lb/gal final working fluid. The process in the following example is identical to the earlier example of mixing two known fluids to achieve a fluid of a certain target density. It uses Equation 8 on page 60 and Equation 9 on page 62. Table 12, which follows the example, provides cutback values for 19.2 lb/gal zinc bromide ($ZnBr_2$).

EXAMPLE J. Determining the Fraction of 19.2 lb/gal $ZnBr_2$ and Fresh Water Required to Prepare one bbl of 15.9 lb/gal Fluid

Find:

v_1, volume

v_2, volume

Given:

v_f = 1.00 bbl

d_f = 15.9 lb/gal

d_1 = 19.2 lb/gal

d_2 = 8.33 lb/gal, fresh water

$$v_1 = \frac{(d_f - d_2)}{(d_1 - d_2)}$$

$$v_1 = \frac{(15.9 \text{ lb/gal} - 8.33 \text{ lb/gal})}{(19.2 \text{ lb/gal} - 8.33 \text{ lb/gal})}$$

$$v_2 = v_f - v_1$$

$$v_2 = 1.00 \text{ bbl} - 0.696 \text{ bbl}$$

Answers:

v_1 = 0.696 bbl

v_2 = 0.304 bbl

For a 15.9 lb/gal working fluid, your pill will have the proportions of 0.696 bbl 19.2 lb/gal spike fluid and 0.304 bbl fresh water.

TABLE 12. 19.2 lb/gal Zinc Bromide ($ZnBr_2$) Cutback Table

Volume in Barrels of 19.2 $ZnBr_2$ and Fresh Water				
Target Density	Water	19.2 $ZnBr_2$	lb $ZnBr_2$	% $ZnBr_2$
d_f[1]	bbl	bbl	lb/bbl	wt%
13.5	0.524	0.476	210.9	37.2%
13.6	0.515	0.485	215.0	37.6%
13.7	0.506	0.494	219.1	38.1%
13.8	0.497	0.503	223.2	38.5%
13.9	0.488	0.512	227.3	38.9%
14.0	0.478	0.522	231.3	39.3%
14.1	0.469	0.531	235.4	39.8%
14.2	0.460	0.540	239.5	40.2%
14.3	0.451	0.549	243.6	40.6%

[1]Densities are approximate.

TABLE 12. **19.2 lb/gal Zinc Bromide ($ZnBr_2$) Cutback Table**

Target Density	Volume in Barrels of 19.2 $ZnBr_2$ and Fresh Water			
	Water	19.2 $ZnBr_2$	lb $ZnBr_2$	% $ZnBr_2$
d_f[1]	bbl	bbl	lb/bbl	wt%
14.4	0.442	0.558	247.7	41.0%
14.5	0.432	0.568	251.7	41.3%
14.6	0.423	0.577	255.8	41.7%
14.7	0.414	0.586	259.9	42.1%
14.8	0.405	0.595	264.0	42.5%
14.9	0.396	0.604	268.1	42.8%
15.0	0.386	0.614	272.2	43.2%
15.1	0.377	0.623	276.2	43.6%
15.2	0.368	0.632	280.3	43.9%
15.3	0.359	0.641	284.4	44.3%
15.4	0.350	0.650	288.5	44.6%
15.5	0.340	0.660	292.6	44.9%
15.6	0.331	0.669	296.6	45.3%
15.7	0.322	0.678	300.7	45.6%
15.8	0.313	0.687	304.8	45.9%
15.9	0.304	0.696	308.9	46.3%
16.0	0.294	0.706	313.0	46.6%
16.1	0.285	0.715	317.0	46.9%
16.2	0.276	0.724	321.1	47.2%
16.3	0.267	0.733	325.2	47.5%
16.4	0.258	0.742	329.3	47.8%
16.5	0.248	0.752	333.4	48.1%
16.6	0.239	0.761	337.4	48.4%
16.7	0.230	0.770	341.5	48.7%
16.8	0.221	0.779	345.6	49.0%
16.9	0.212	0.788	349.7	49.3%
17.0	0.202	0.798	353.8	49.5%
17.1	0.193	0.807	357.8	49.8%

[1]Densities are approximate.

TETRAVis L Plus Curves

TETRAVis L Plus is TETRA's proprietary blend of prehydrated hydroxyethyl cellulose (HEC). The optimum amount of HEC polymer required in completion fluids varies with differences in salt composition and density. The curves in Figure 7 through Figure 15 have been provided as a useful reference. For each brine group, the first illustration shows viscosity in Marsh Funnel seconds at different concentrations of TETRAVis L Plus in gal/bbl. The second illustration for each brine group shows yield point at different concentrations of TETRAVis L Plus in gal/bbl. The final illustration for each brine group shows plastic viscosity at different concentrations of TETRAVis L Plus in gal/bbl.

TETRA recommends using TETRAVis L Plus for most applications because it is prehydrated and, thus, more cost effective.

FIGURE 7. Marsh Funnel Viscosity of Low Density CBFs

(Measured at 75°F)

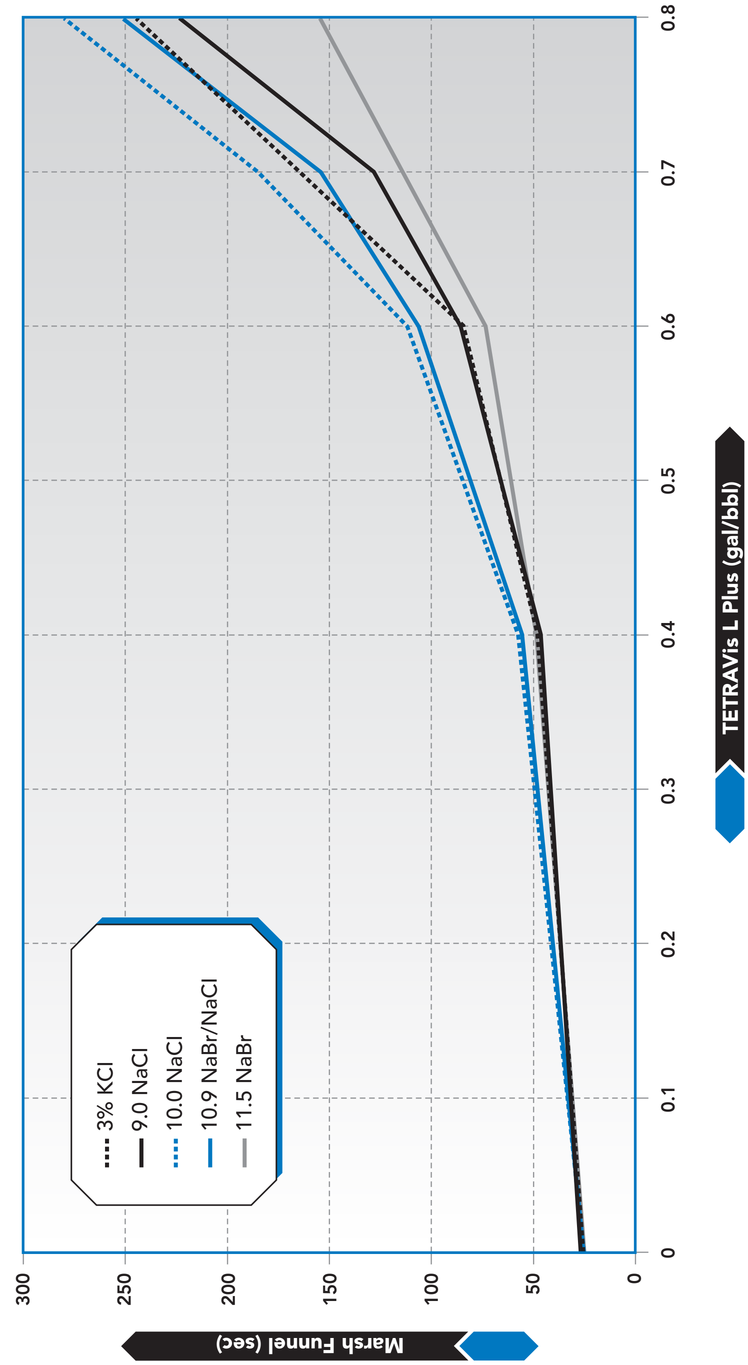


FIGURE 8. Yield Point of Low Density CBFs

(Measured at 75°F)

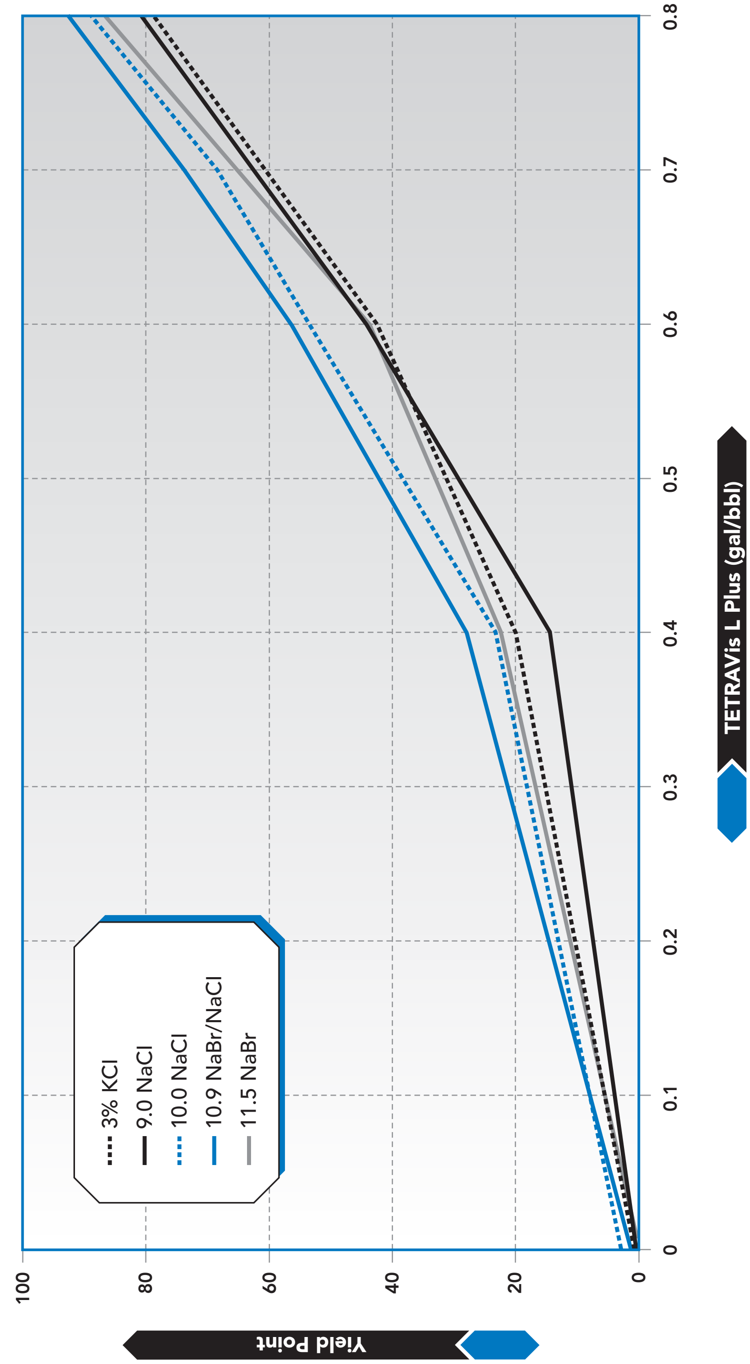


FIGURE 9. Plastic Viscosity of Low Density CBFs

(Measured at 75°F)

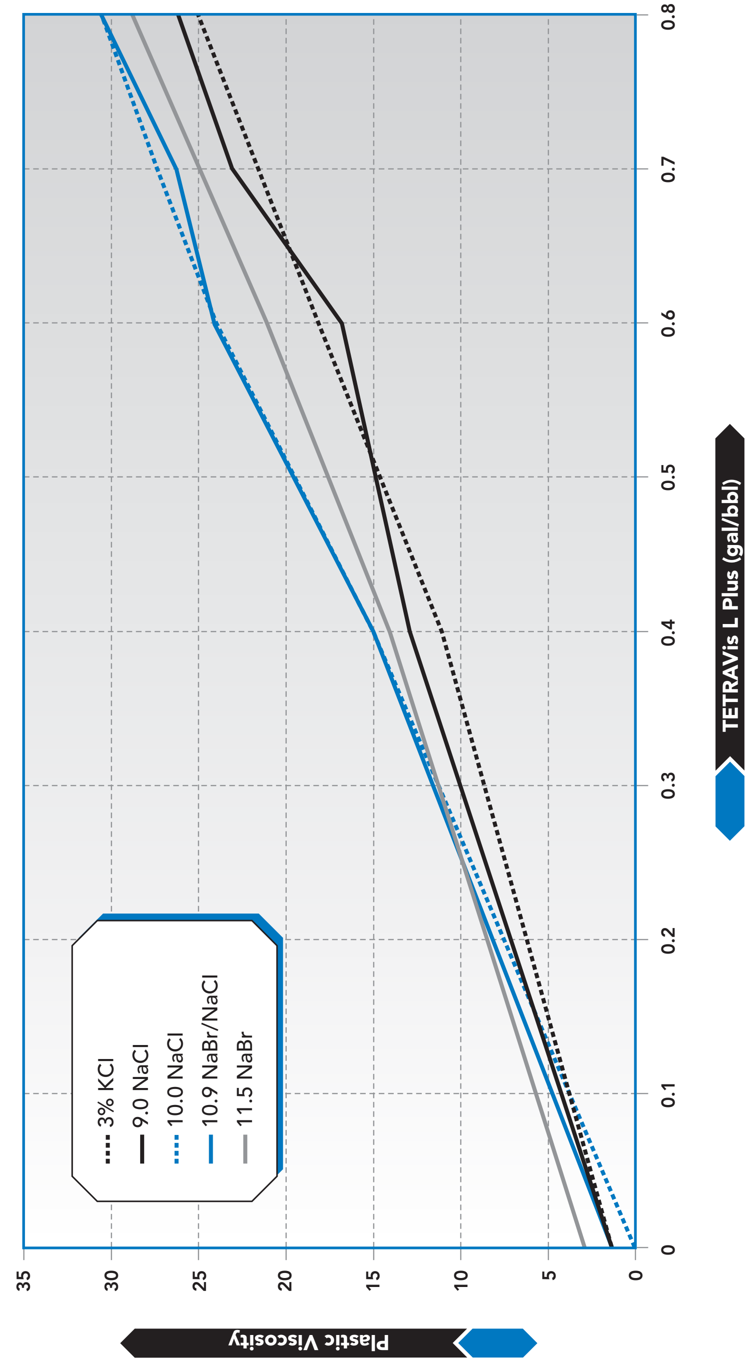


FIGURE 10. Marsh Funnel Viscosity of Calcium Brines

(Measured at 75°F)

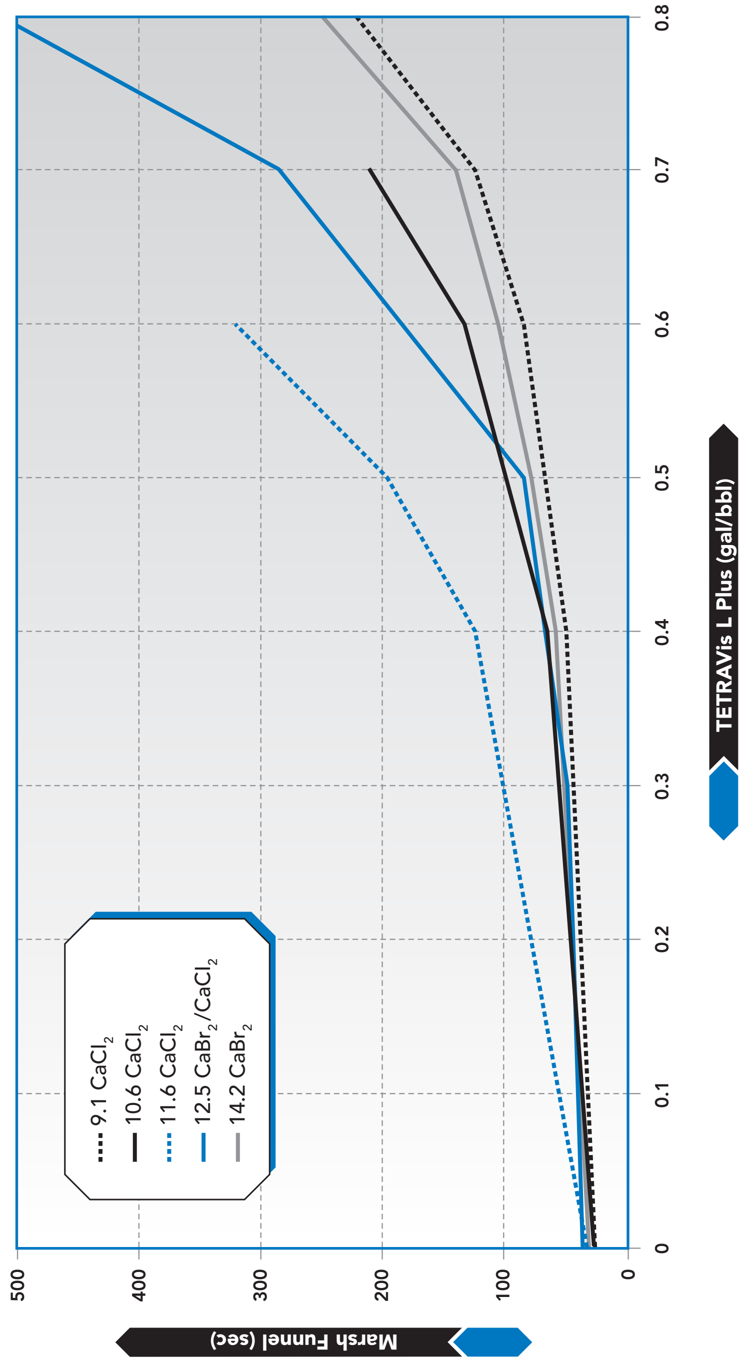


FIGURE 11. Yield Point of Calcium Brines

(Measured at 75°F)

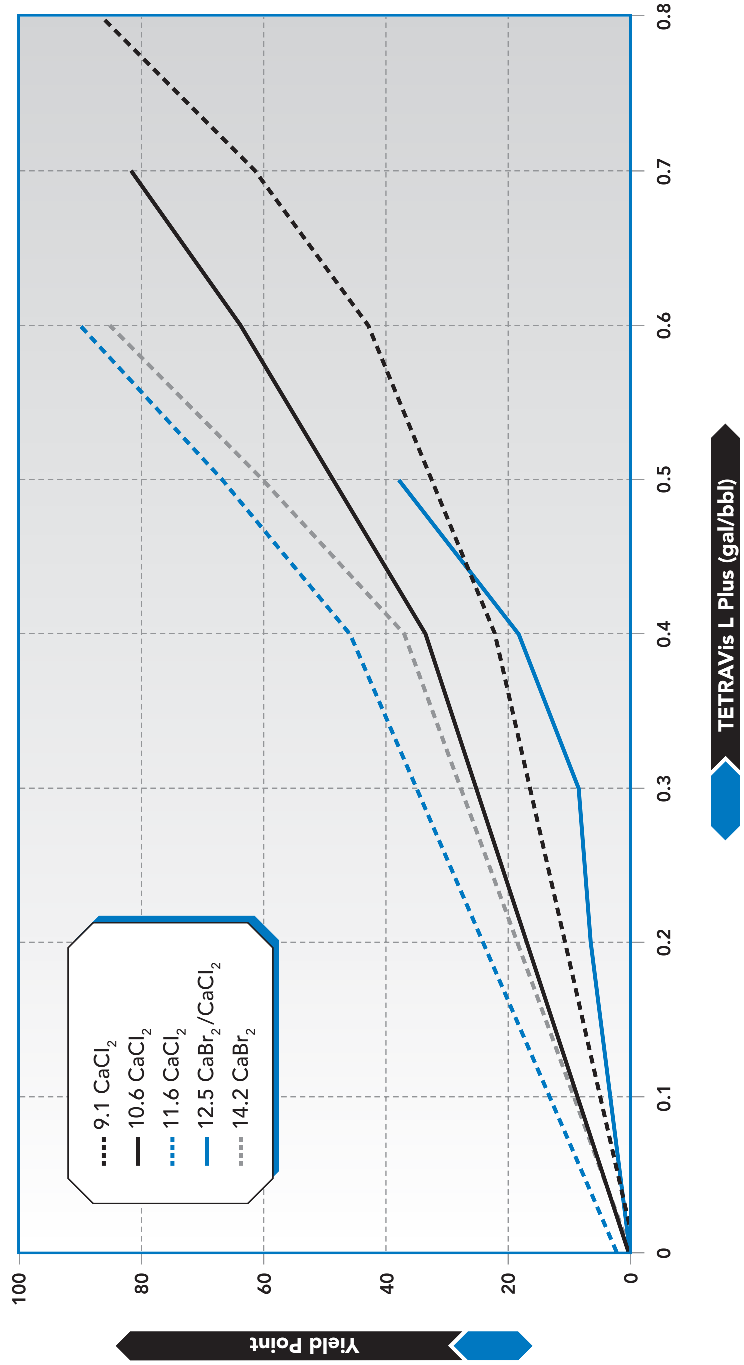


FIGURE 12. Plastic Viscosity of Calcium Brines

(Measured at 75°F)

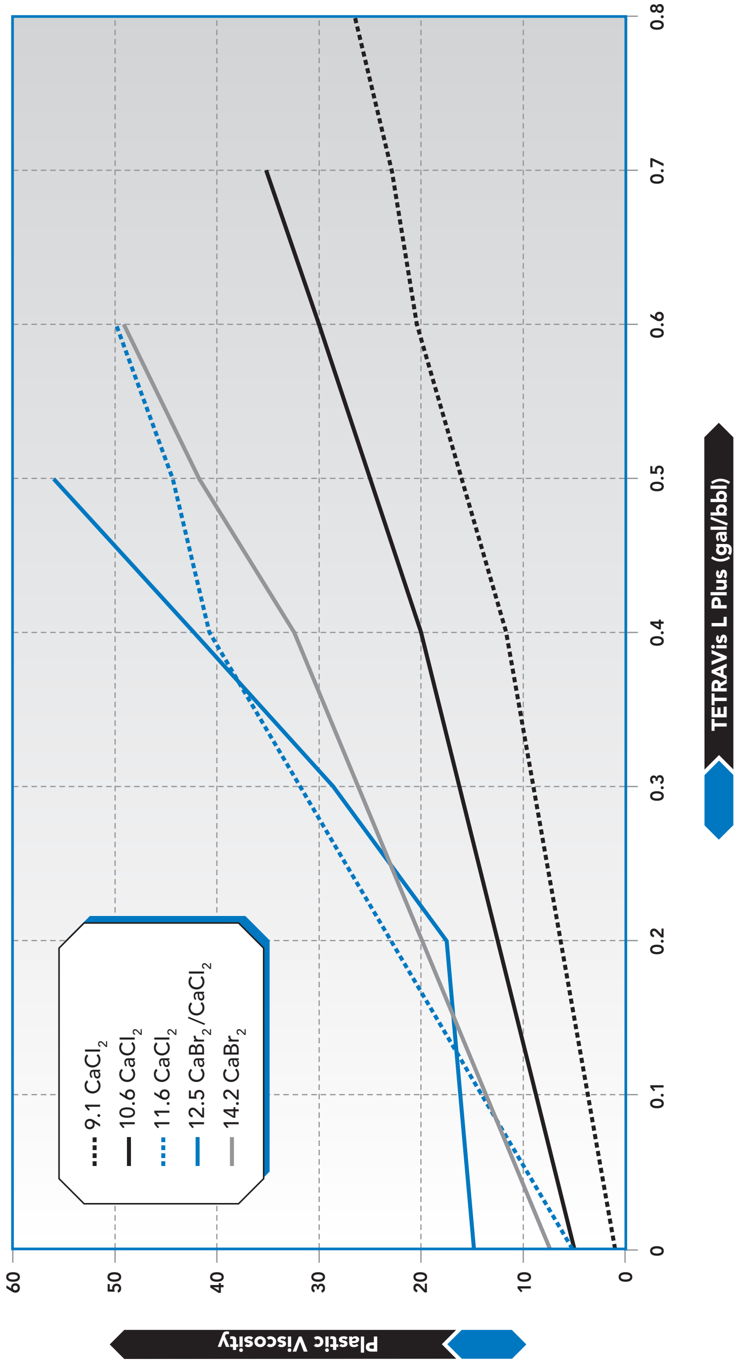


FIGURE 13. Marsh Funnel Viscosity of Zinc/Calcium Bromide Brines

(Measured at 75°F)

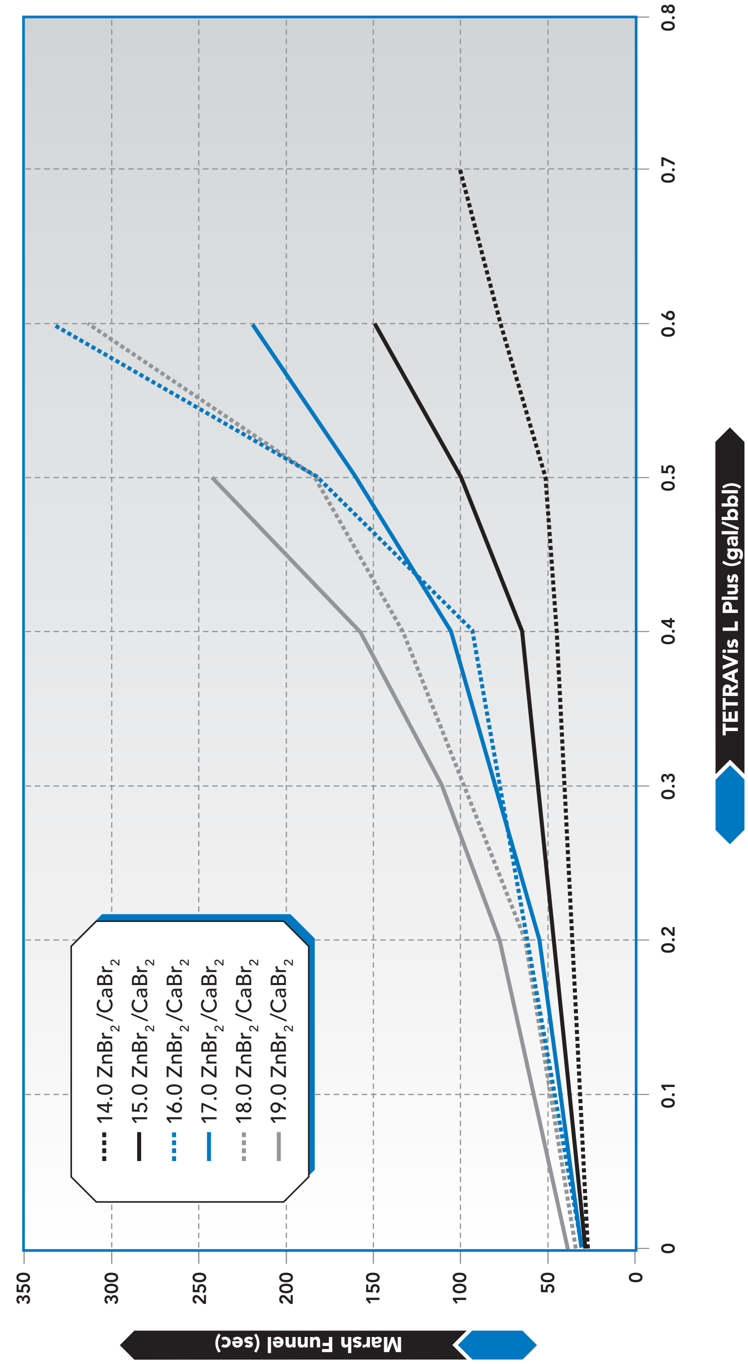


FIGURE 14. Yield Point of Zinc/Calcium Bromide Brines

(Measured at 75°F)

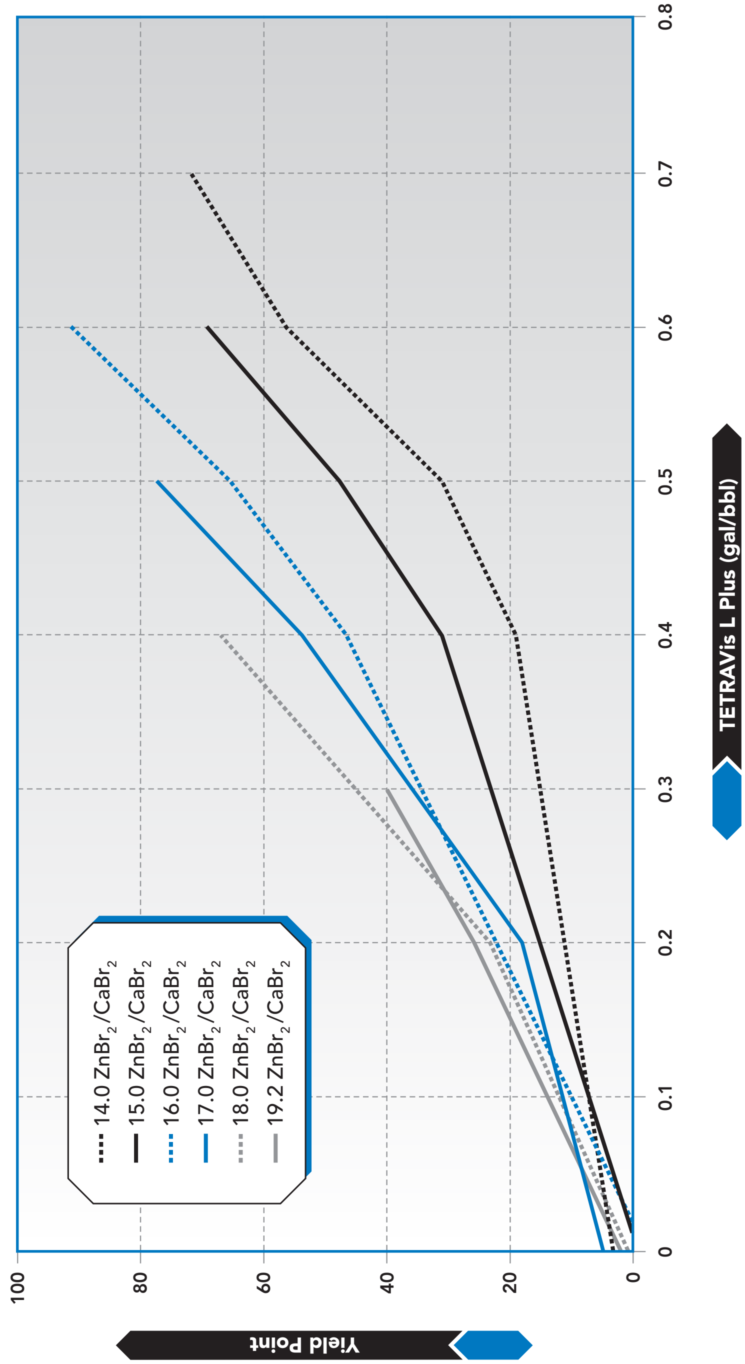
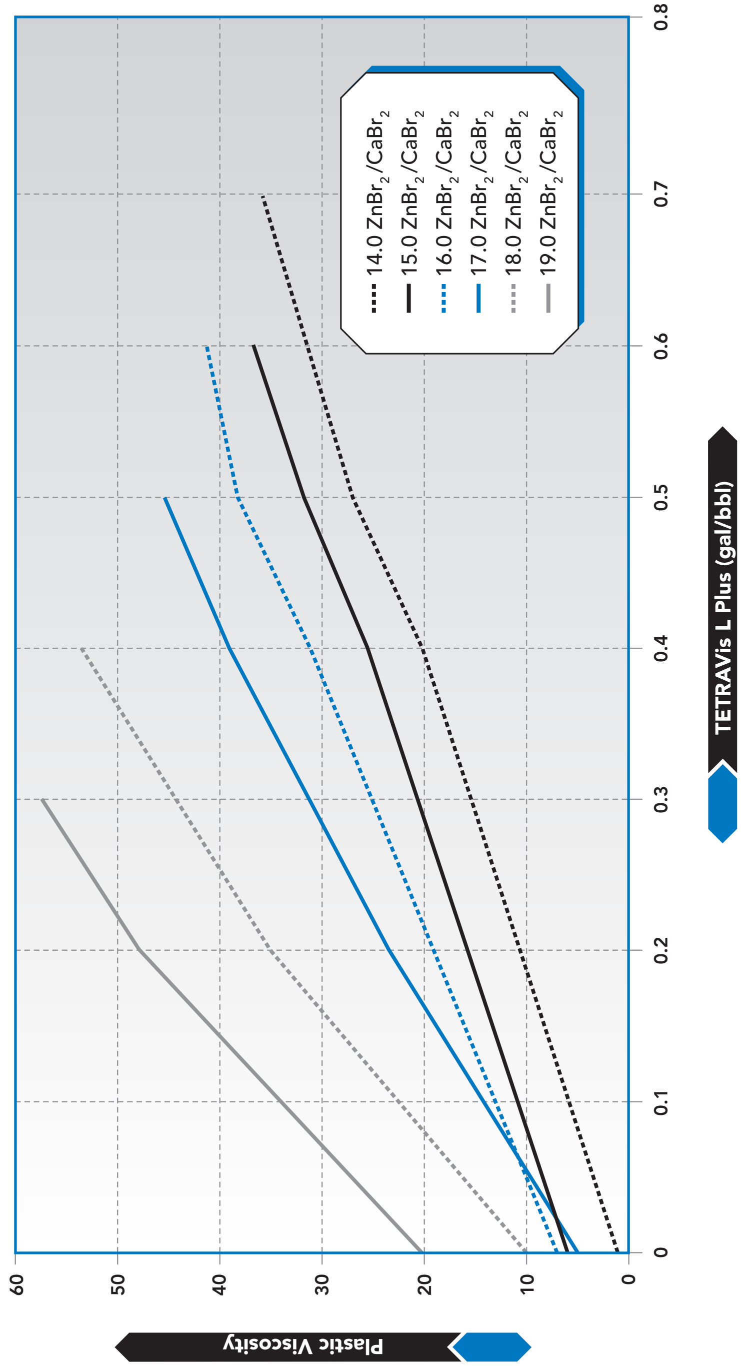


FIGURE 15. Plastic Viscosity of Zinc/Calcium Bromide Brines

(Measured at 75°F)



Blending Equipment

In viscosifying any CBF, vigorous agitation is essential for efficient polymer hydration. This is especially critical for the dry product. You have a number of options when it comes to suitable blending equipment:

1. Usually the best available equipment for blending TETRAVis pills on location is a sand control blender.
2. Cement unit displacement tanks can be used for blending TETRAVis pills on location.
3. The rig slugging pit can also be used for blending TETRAVis pills at the rig site; however, due to their low energy shearing action, they are less cost effective than other options.

Spotting Balanced Pills

A balanced pill is a volume of viscous material (pill or plug) placed in the bottom of the working string and up into the casing or liner, such that the fluid column of the viscous pill in the working string is the same height as the column of pill fluid in the annulus. The pill is balanced to the degree that the total fluid column in the working string and the annulus provide the same hydrostatic head at the bottom of the working string. When placing the balanced pill to slow fluid loss, pill volume should include both the length of area of fluid loss plus some volume for anticipated loss.

If you know the length of the interval that you want the pill to occupy (h_{bal}), calculate the pill volume (v_{pill}) using Equation 16. Values for the tubing and annular capacities are found in Table 19, "API Tubing — Weight, Dimensions, and Capacities," on page 135 and Table 20, "Annular Capacity," on page 138.

EQUATION 16.

$$v_{pill} = (C_{an} + C_t) * h_{bal}$$

v_{pill} = volume of balanced pill, bbl
C_{an} = capacity of annulus, bbl/ft
C_t = capacity of tubing, bbl/ft
h_{bal} = length of pill planned, ft

EXAMPLE K. Balanced Pill in a Known Interval

Find:

v_{pill}, volume of balanced pill

Given:

C_{an} = 0.03055 bbl/ft

C_t = 0.00264 bbl/ft

h_{bal} = 95 ft

casing = 6-5/8", 20.00 lb/ft, 6.049" ID

tubing = 1-7/8", 2.4 lb/ft, 1.65" ID

$$v_{pill} = (C_{an} + C_t) * h_{bal}$$

$$v_{pill} = (0.03055 \text{ bbl/ft} + 0.00264 \text{ bbl/ft}) * 95 \text{ ft}$$

Answer:

v_{pill} = 3.2 bbl

Another approach to spotting a pill or plug is to find out how much footage a pill of a given volume will cover if it is balanced in the tubing and annulus. In this case, you will already know the starting volume of the pill in barrels.

EQUATION 17.

$$h_{bal} = \frac{v_{pill}}{(C_t + C_{an})}$$

h_{bal} = length of pill planned, ft

v_{pill} = volume of balanced pill, bbl

C_t = capacity of tubing, bbl/ft

C_{an} = capacity of annulus, bbl/ft

EXAMPLE L. Balanced Pill of Known Volume

Find:

h_{bal}, length of pill planned

Given:

v_{pill} = 5 bbl

C_t = 0.00264 bbl/ft

C_{an} = 0.03055 bbl/ft

casing = 6-5/8", 20.00 lb/ft, 6.049" ID

tubing = 1-7/8", 2.4 lb/ft, 1.65" ID

$$h_{bal} = \frac{v_{pill}}{(C_{an} + C_t)}$$

$$h_{bal} = \frac{5 \text{ bbl}}{(0.03055 \text{ bbl/ft} + 0.00264 \text{ bbl/ft})}$$

Answer:

h_{bal} = 151 ft

Spotting the pill at the correct depth means that you need to chase it with a volume of working fluid that will leave it at the same height in the tubing and outside in the annulus. To find the chase volume, determine the total volume of the tubing and subtract the interval height (h_{bal}) that you want left in the tubing. Also, make sure to add in the volume of the lines from the pit to the drill floor (v_{surf}).

EQUATION 18.

$$v_{chase} = C_t * (h - h_{bal}) + v_{surf}$$

v_{chase} = volume of chase fluid, bbl
C_t = capacity of tubing, bbl/ft
h = total length of tubing, ft
h_{bal} = length of pill planned, ft
v_{surf} = volume of empty lines from pit to drill floor, bbl

EXAMPLE M. Chase Volume to Place a Balanced Pill

Find:

v_{chase}, volume of chase fluid

Given:

C_t = 0.00264 bbl/ft

h = 6,000 ft

h_{bal} = 95 ft

v_{surf} = 4 bbl

tubing = 1-7/8", 2.4 lb/ft, 1.65" ID

$$v_{chase} = C_t * (h - h_{bal}) + v_{surf}$$

$$v_{chase} = 0.00264 \text{ bbl/ft} * (6000 \text{ ft} - 95 \text{ ft}) + 4 \text{ bbl}$$

Answer:

v_{chase} = 19.6 bbl

Slug Calculations

At times, it may be necessary to depress the standing fluid level in the drill pipe or working string with a CBF in the hole. A slug fluid is usually a stock blending fluid like 11.6 lb/gal $CaCl_2$, 14.2 lb/gal $CaBr_2$, or 19.2 lb/gal $Zn/CaBr_2$, depending on the type of fluid being used as the working fluid.

This is a three step process:

1. Find the pressure differential (P_{dif}) needed to attain the number of feet of dry or empty working string.

EQUATION 19.

$$P_{dif} = d * h_{dry} * 0.052$$

P_{dif} = pressure differential, psi
d = density of fluid in well, lb/gal
h_{dry} = length of dry pipe, ft
0.052 = units conversion factor, gal/in^2-ft

2. Knowing the weight of the stock slug fluid, calculate the number of feet required (h_{slug}) to achieve the desired depression in the fluid level.

EQUATION 20.

$$h_{slug} = \frac{P_{dif}}{(d_{slug} - d) * 0.052}$$

h_{slug} = length of slug fluid required, ft
d_{slug} = density of slug fluid, lb/gal
P_{dif} = pressure differential from previous step, psi
d = density of fluid in well, lb/gal
0.052 = units conversion factor, gal/in^2-ft

3. Convert the feet of slug fluid to volume of slug fluid in barrels (v_{slug}) using the inside volume of the drill pipe from Table 17, "API Drill Pipe Capacity and Displacement," on page 132 or Table 19, "API Tubing — Weight, Dimensions, and Capacities," on page 135.

EQUATION 21.

$$v_{slug} = h_{slug} * C_t$$

v_{slug} = volume of slug, bbl
h_{slug} = length of slug fluid required, ft
C_t = internal capacity of drill pipe or tubing, bbl/ft

EXAMPLE N. Slug Calculation

Find:

P_{dif}, pressure differential

h_{slug}, feet of slug fluid

v_{slug}, volume of slug

Given:

d = 12.6 lb/gal

h_{dry} = 100 ft

d_{slug} = 14.2 lb/gal

C_t = 0.00264 bbl/ft

$$P_{dif} = d * h_{dry} * 0.052$$

$$P_{dif} = 12.6 \text{ lb/gal} * 100 \text{ ft} * 0.052$$

$$h_{slug} = \frac{P_{dif}}{(d_{slug} - d) * 0.052}$$

$$h_{slug} = \frac{65.5 \text{ psi}}{(14.2 \text{ lb/gal} - 12.6 \text{ lb/gal}) * 0.052}$$

$$v_{slug} = h_{slug} * C_t$$

$$v_{slug} = 787 \text{ ft} * 0.00264 \text{ bbl/ft}$$

Answers:

P_{dif} = 65.5 psi

h_{slug} = 787 ft

v_{slug} = 2.08 bbl

Notes:

Notes:

Notes: