CHAPTER 2 Fluid Planning: Fluid Selection

This chapter and Chapter 3 of the *Engineered Solutions Guide for Clear Brine Fluids and Filtration* are designed to take you through the decision making process and assist with the planning and development of a well completion project.

This chapter will cover:

1. Safety and the Environment
2. The Planning Process
3. Fluid Categories
4. Fluid Density
5. Crystallization Temperature
6. Temperature and Pressure Effects
7. Estimating Required Fluid Volume
8. Fluid Compatibility

Safety and the Environment

We begin with a brief reminder about the importance of safety and the environment when working with clear brine fluids and chemical additives. The field of safety and environmental protection is broad, constantly evolving, and is outside the realm of this document, which should only be viewed as a brief introduction. You have two primary resources in these areas. Your main resource should be the safety and environmental professionals within your company. The regulatory agencies themselves are a second valuable resource. There are many regulatory agencies in the oil and gas producing regions of the world. Information provided in this guide is applicable to the United States and associated offshore areas.

An overview of these topics is provided in Chapter 7, "U.S. Safety and Environmental Information," which should be read in its entirety before bringing a clear brine fluid (CBF) to any well location.

Personal Safety

An understanding of the nature of CBFs will reduce the risk of personal injury to those using these materials while conducting completion and workover operations.

Clear brine fluids are highly concentrated mixtures of inorganic salts, usually chlorides and bromides. These fluids have an affinity for water and will even absorb water from the air. Should concentrated brines come into contact with a person's skin, this same strong tendency to absorb water will cause drying of the skin and, in extreme cases, can even cause a burn-like reddening and blistering.

All precautions should be taken to prevent direct contact between clear brine fluids and the body, especially the eyes and mucous membranes.

Safe work practices should be implemented to reduce worker exposure to CBFs. When engineering controls are not feasible to prevent exposure, a risk assessment should be conducted and administrative controls should be initiated that will reduce employee exposure to an acceptable level.

A properly completed Job Safety/Environmental Analysis (JSEA) will help to establish these conditions.

Employees who work with or around clear brine fluids should participate in a safety meeting before any work begins. As previously noted, a more detailed discussion of safety precautions and appropriate equipment is provided in Chapter 7, "U.S. Safety and Environmental Information," later in the guide.

Environmental Considerations

The constituents of clear brine fluids are common salts and, except for those containing zinc bromide, can be rendered harmless to the environment with the addition of sufficient water. Offshore discharges of CBFs to the environment fall under the regulations of the National Pollutant Discharge Elimination System (NPDES). Zinc bromide is considered a priority pollutant under NPDES and cannot be legally discharged.

All precautions should be taken to ensure that fluids and additives are not lost to the environment in an uncontrolled manner. In the event that this does happen, immediate notification to the National Response Center and other regulatory authorities is required if the released fluid contains zinc bromide, ammonium chloride, or one of the TETRA additives listed in Table 49 on page 175 in an amount greater than the established EPA reportable quantity (RQ). Because environmental regulations can change, always involve your company's environmental professionals when planning any completion or workover project.

⚠ *Under EPA regulations, spills of completion fluids containing zinc bromide or ammonium chloride must be immediately reported to the National Response Center at 1.800.424.8802 if:*

- *the quantity of zinc bromide in the spill exceeds the 1,000 lb RQ for zinc bromide, or*
- *the quantity of ammonium chloride in the spill exceeds the 5,000 lb RQ for ammonium chloride.*

See Chapter 7, "U.S. Safety and Environmental Information," for more information on this subject.

The Planning Process

Design Rationale

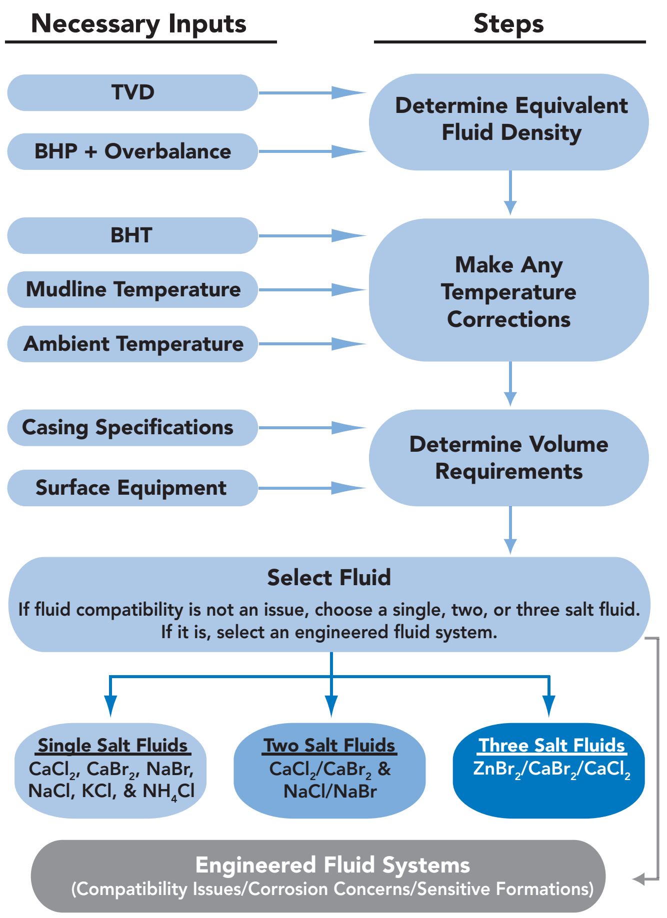
The planning process steps are organized in such a way as to assist you in using basic pieces of information to develop a coherent project plan that encompasses all aspects of selecting the correct clear brine fluid, additives, and associated equipment. Many calculations have been formatted as tables or charts in order to help you quickly narrow your choices. There will also be circumstances that are unconventional or non-routine. In these cases, equations and appropriate units of measurement have been provided to facilitate the use of a handheld calculator.

The planning process steps are arranged to enable you to:

1. determine appropriate fluid density using true vertical depth (TVD), bottomhole pressure (BHP), and bottomhole temperature (BHT);
2. select the correct true crystallization temperature (TCT);
3. estimate the volume of clear brine fluid for the job;
4. select the proper clear brine fluid family (single, two, or three salt); or
5. where compatibility issues, corrosion concerns, or sensitive formations exist, select an engineered fluid system such as a MatchWell™ compatibility selected fluid system or a specialty fluid with a PayZone® formation protection additive package.

Figure 1 provides a conceptual flow of the fluid selection process in normal or non-high pressure, high temperature (HPHT) wells where the use of carbon steel tubing is planned. Required information or inputs are shown as arrows entering from the left. The flow steps run from top to bottom on the right.

FIGURE 1. Fluid Selection Process



Planning for Wells Requiring Corrosion Resistant Alloys

Given the potential for environmentally assisted cracking (EAC) in wells where corrosion resistant alloy (CRA) tubing will be used, especially in HPHT wells, the fluid selection process is different than that outlined above for traditional well completions. Rather than selecting the fluid at the end of the process, as is done in traditional completions, metallurgy and fluids should be selected concurrently for wells where a CRA will be used with a packer fluid. In these wells, it is important to take steps to decrease the probability of EAC by selecting the best combination of metallurgy and clear brine fluid for the specific well conditions. In an effort to better understand EAC, TETRA has participated in extensive testing and, through this testing, has developed the MatchWell fluid compatibility selector. This specialty software is designed to provide customer recommendation reports that identify compatible and cost effective metallurgy/fluid combinations.

Fluid Categories

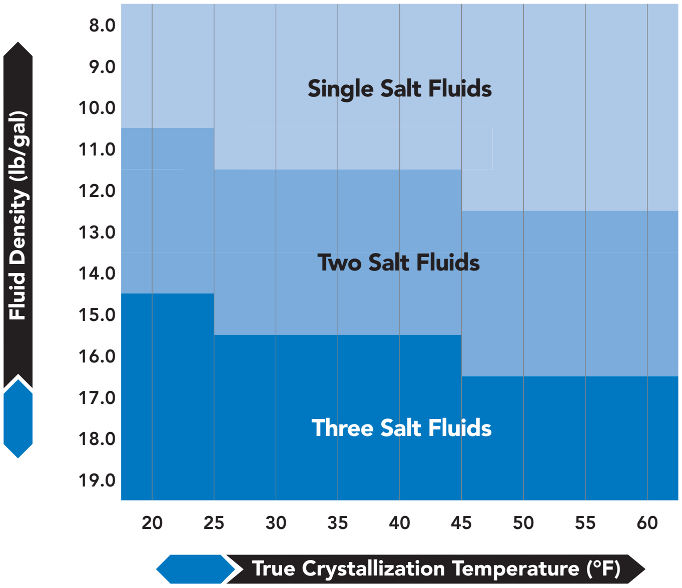
In reality, planning any completion is an iterative process and will most likely require more than one pass as you gather more information and refine your selection. Using basic design information, true vertical depth, bottomhole pressure, and environmental temperature considerations as outlined in the following sections, you can determine which clear brine fluids are a good match for the conditions.

Low density systems usually consist of single salt fluids, which can range in density from slightly above the density of water, such as 3% potassium chloride (KCl), to as high as 11.6 lb/gal calcium chloride ($CaCl_2$). Unique formation properties or concerns about the compatibility of conventional brines with formation water may suggest the use of sodium bromide (NaBr), calcium bromide ($CaBr_2$), sodium formate (NaO_2CH), potassium formate (KO_2CH), or cesium formate (CsO_2CH)—the latter three of which are halide free, containing no chloride or bromide.

Midrange density fluids, 11.7 lb/gal to 15.1 lb/gal, are typically two salt mixtures of calcium chloride ($CaCl_2$) and calcium bromide ($CaBr_2$). The boundary between two and three salt fluids in Figure 2 is influenced by the lower of the expected atmospheric temperature or mudline temperature. In many cases, the lowest temperature in the entire fluid column is at the ocean floor (mudline) where temperatures can routinely be less than 40°F. This temperature will often dictate the CBF category that is available to you.

FIGURE 2. Fluid Categories

(Density vs. True Crystallization Temperature)



Fluid Density

Expected bottomhole conditions are the basic criteria that influence the selection of a clear brine completion fluid. The fluid density required for a job is largely determined by the true vertical depth (TVD) planned for the well and the expected bottomhole pressure (BHP). True vertical depth is normally given in feet (ft), and bottomhole pressure is given in pounds per square inch (psi or lb/in^2). These two values are used to determine the pressure gradient in pounds per square inch per foot of depth (psi/ft). An additional margin of safety should be added to the BHP to ensure that control of the well is achieved, usually 200 to 400 psi. The safe bottomhole pressure (noted as BHP$_s$) and TVD are both used in Equation 1 to find the pressure gradient.

EQUATION 1.

$$grad_s = \frac{BHP_s}{TVD}$$

$grad_s$ = safe pressure gradient, psi/ft
BHP_s = safe bottomhole pressure, psi or lb/in^2
TVD = true vertical depth, ft

The pressure gradient can be converted to density in pounds per gallon (lb/gal) by a change of units, shown in Equation 2.

EQUATION 2.

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

d_u = fluid density, uncorrected for T and P, lb/gal

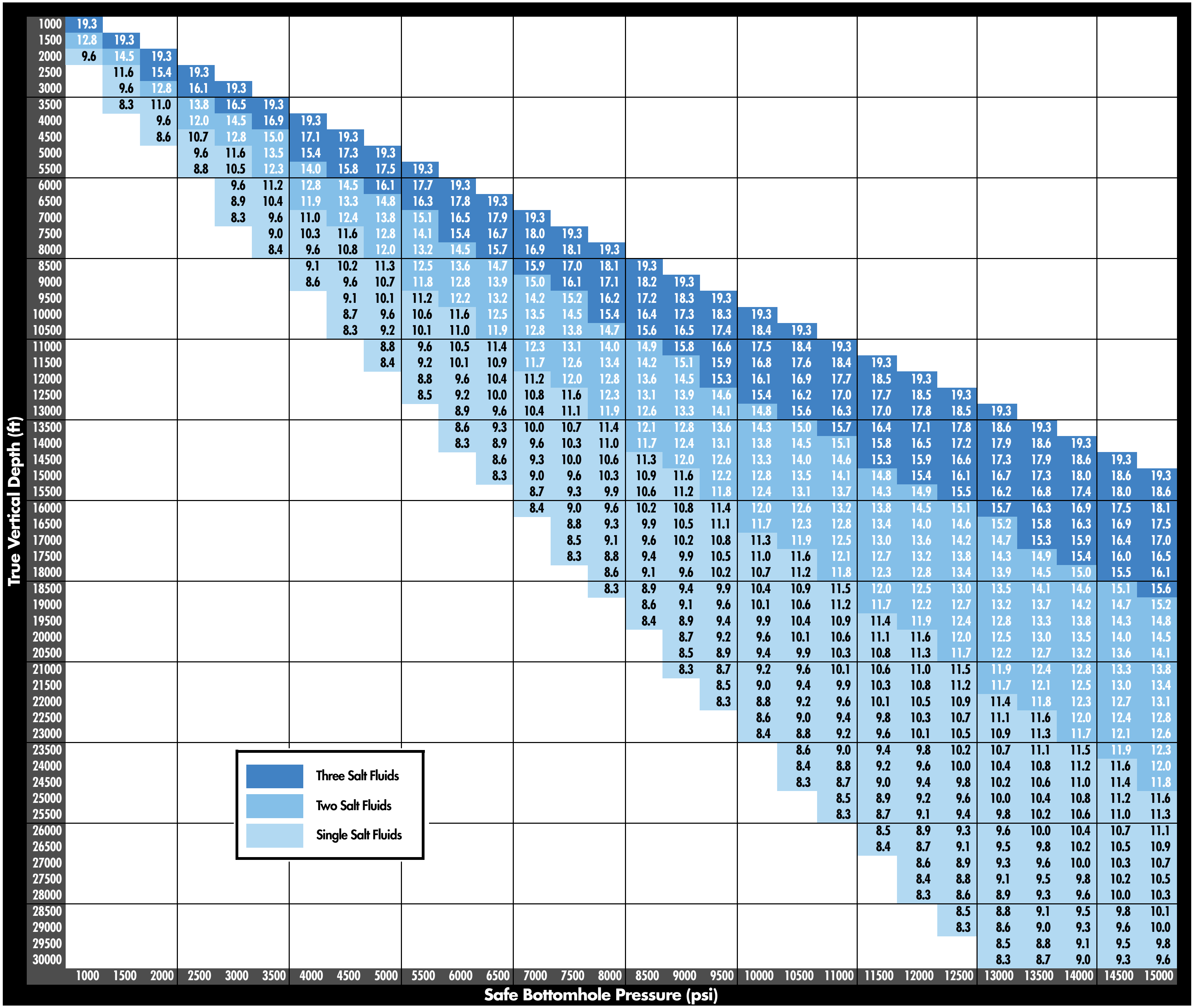
grad = pressure gradient, psi/ft

0.052 = units conversion factor, gal/in^2-ft

As an alternative, the values for TVD and BHP_s can be used to find the required fluid density using Figure 3. This density value is the effective fluid density that will be required to balance the pressure exerted by the fluids in the formation. The colored regions in Figure 3 correspond to the fluid families: single salt, two salt, and three salt.

Open this foldout page to view Figure 3, which shows fluid density in lb/gal based on true vertical depth in feet and safe bottomhole pressure in psi.

FIGURE 3. TVD-BHP Fluid Density Chart



Safe Bottomhole Pressure (psi)

True Vertical Depth (ft)	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000	10500	11000	11500	12000	12500	13000	13500	14000	14500	15000
1000	19.3																												
1500	12.8	19.3																											
2000	9.6	14.5	19.3																										
2500		11.6	15.4	19.3																									
3000		9.6	12.8	16.1	19.3																								
3500		8.3	11.0	13.8	16.5	19.3																							
4000			9.6	12.0	14.5	16.9	19.3																						
4500			8.6	10.7	12.8	15.0	17.1	19.3																					
5000				9.6	11.6	13.5	15.4	17.3	19.3																				
5500				8.8	10.5	12.3	14.0	15.8	17.5	19.3																			
6000					9.6	11.2	12.8	14.5	16.1	17.7	19.3																		
6500					8.9	10.4	11.9	13.3	14.8	16.3	17.8	19.3																	
7000					8.3	9.6	11.0	12.4	13.8	15.1	16.5	17.9	19.3																
7500						9.0	10.3	11.6	12.8	14.1	15.4	16.7	18.0	19.3															
8000						8.4	9.6	10.8	12.0	13.2	14.5	15.7	16.9	18.1	19.3														
8500							9.1	10.2	11.3	12.5	13.6	14.7	15.9	17.0	18.1	19.3													
9000							8.6	9.6	10.7	11.8	12.8	13.9	15.0	16.1	17.1	18.2	19.3												
9500								9.1	10.1	11.2	12.2	13.2	14.2	15.2	16.2	17.2	18.3	19.3											
10000								8.7	9.6	10.6	11.6	12.5	13.5	14.5	15.4	16.4	17.3	18.3	19.3										
10500								8.3	9.2	10.1	11.0	11.9	12.8	13.8	14.7	15.6	16.5	17.4	18.4	19.3									
11000									8.8	9.6	10.5	11.4	12.3	13.1	14.0	14.9	15.8	16.6	17.5	18.4	19.3								
11500									8.4	9.2	10.1	10.9	11.7	12.6	13.4	14.2	15.1	15.9	16.8	17.6	18.4	19.3							
12000										8.8	9.6	10.4	11.2	12.0	12.8	13.6	14.5	15.3	16.1	16.9	17.7	18.5	19.3						
12500										8.5	9.2	10.0	10.8	11.6	12.3	13.1	13.9	14.6	15.4	16.2	17.0	17.7	18.5	19.3					
13000											8.9	9.6	10.4	11.1	11.9	12.6	13.3	14.1	14.8	15.6	16.3	17.0	17.8	18.5	19.3				
13500											8.6	9.3	10.0	10.7	11.4	12.1	12.8	13.6	14.3	15.0	15.7	16.4	17.1	17.8	18.6	19.3			
14000											8.3	8.9	9.6	10.3	11.0	11.7	12.4	13.1	13.8	14.5	15.1	15.8	16.5	17.2	17.9	18.6	19.3		
14500												8.6	9.3	10.0	10.6	11.3	12.0	12.6	13.3	14.0	14.6	15.3	15.9	16.6	17.3	17.9	18.6	19.3	
15000												8.3	9.0	9.6	10.3	10.9	11.6	12.2	12.8	13.5	14.1	14.8	15.4	16.1	16.7	17.3	18.0	18.6	19.3
15500													8.7	9.3	9.9	10.6	11.2	11.8	12.4	13.1	13.7	14.3	14.9	15.5	16.2	16.8	17.4	18.0	18.6
16000													8.4	9.0	9.6	10.2	10.8	11.4	12.0	12.6	13.2	13.8	14.5	15.1	15.7	16.3	16.9	17.5	18.1
16500														8.8	9.3	9.9	10.5	11.1	11.7	12.3	12.8	13.4	14.0	14.6	15.2	15.8	16.3	16.9	17.5
17000														8.5	9.1	9.6	10.2	10.8	11.3	11.9	12.5	13.0	13.6	14.2	14.7	15.3	15.9	16.4	17.0
17500														8.3	8.8	9.4	9.9	10.5	11.0	11.6	12.1	12.7	13.2	13.8	14.3	14.9	15.4	16.0	16.5
18000															8.6	9.1	9.6	10.2	10.7	11.2	11.8	12.3	12.8	13.4	13.9	14.5	15.0	15.5	16.1
18500															8.3	8.9	9.4	9.9	10.4	10.9	11.5	12.0	12.5	13.0	13.5	14.1	14.6	15.1	15.6
19000																8.6	9.1	9.6	10.1	10.6	11.2	11.7	12.2	12.7	13.2	13.7	14.2	14.7	15.2
19500																8.4	8.9	9.4	9.9	10.4	10.9	11.4	11.9	12.4	12.8	13.3	13.8	14.3	14.8
20000																	8.7	9.2	9.6	10.1	10.6	11.1	11.6	12.0	12.5	13.0	13.5	14.0	14.5
20500																	8.5	8.9	9.4	9.9	10.3	10.8	11.3	11.7	12.2	12.7	13.2	13.6	14.1
21000																	8.3	8.7	9.2	9.6	10.1	10.6	11.0	11.5	11.9	12.4	12.8	13.3	13.8
21500																		8.5	9.0	9.4	9.9	10.3	10.8	11.2	11.7	12.1	12.5	13.0	13.4
22000																		8.3	8.8	9.2	9.6	10.1	10.5	10.9	11.4	11.8	12.3	12.7	13.1
22500																			8.6	9.0	9.4	9.8	10.3	10.7	11.1	11.6	12.0	12.4	12.8
23000																			8.4	8.8	9.2	9.6	10.1	10.5	10.9	11.3	11.7	12.1	12.6
23500																				8.6	9.0	9.4	9.8	10.2	10.7	11.1	11.5	11.9	12.3
24000																				8.4	8.8	9.2	9.6	10.0	10.4	10.8	11.2	11.6	12.0
24500																				8.3	8.7	9.0	9.4	9.8	10.2	10.6	11.0	11.4	11.8
25000																					8.5	8.9	9.2	9.6	10.0	10.4	10.8	11.2	11.6
25500																					8.3	8.7	9.1	9.4	9.8	10.2	10.6	11.0	11.3
26000																						8.5	8.9	9.3	9.6	10.0	10.4	10.7	11.1
26500																						8.4	8.7	9.1	9.5	9.8	10.2	10.5	10.9
27000																							8.6	8.9	9.3	9.6	10.0	10.3	10.7
27500																							8.4	8.8	9.1	9.5	9.8	10.2	10.5
28000																							8.3	8.6	8.9	9.3	9.6	10.0	10.3
28500																								8.5	8.8	9.1	9.5	9.8	10.1
29000																								8.3	8.6	9.0	9.3	9.6	10.0
29500																									8.5	8.8	9.1	9.5	9.8
30000																									8.3	8.7	9.0	9.3	9.6

General Fluid Density Ranges

Table 1 below provides an extensive list of conventional and specialty clear brine fluids and their working density ranges.

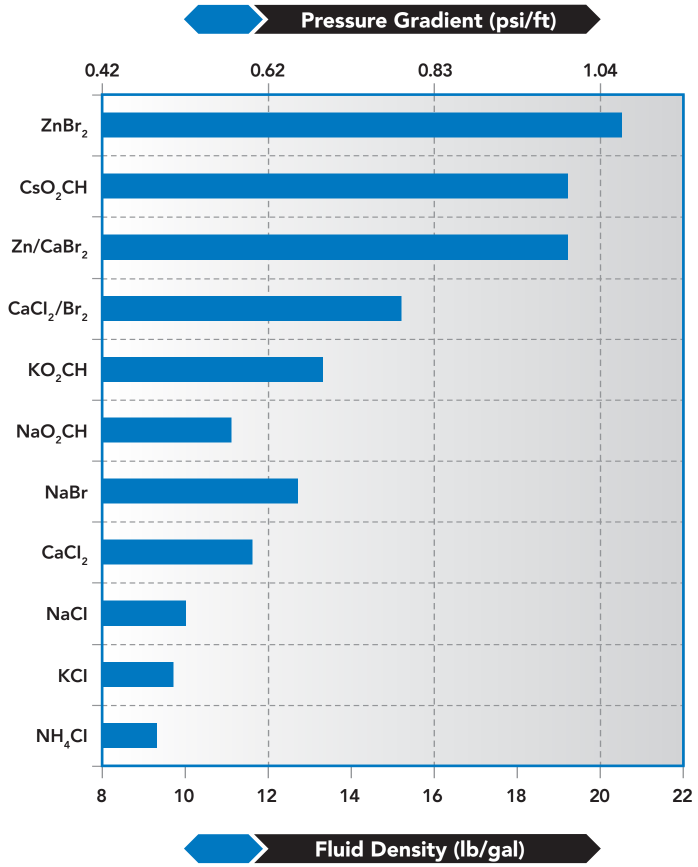
TABLE 1. General Density Ranges for Clear Brine Fluids

Clear Brine Fluid	Density Range
	lb/gal
Ammonium Chloride, NH_4Cl	8.4 - 8.9
Potassium Chloride, KCl	8.4 - 9.7
Potassium-Sodium Chloride, KCl/NaCl	8.4 - 10.0
Sodium Chloride, NaCl	8.4 - 10.0
Sodium Formate, NaO_2CH	8.4 - 11.1
Potassium-Calcium Chloride, $KCl/CaCl_2$	8.4 - 11.6
Calcium Chloride, $CaCl_2$	8.4 - 11.6
Sodium Bromide, NaBr	8.4 - 12.7
Sodium Bromide-Chloride, NaBr/NaCl	8.4 - 12.7
Potassium Formate, KO_2CH	8.4 - 13.1
Calcium Bromide, $CaBr_2$	8.4 - 15.1
Calcium Chloride-Bromide, $CaCl_2/CaBr_2$	11.6 - 15.1
Potassium-Cesium Formate, KO_2CH/CsO_2CH	13.1 - 19.2
Cesium Formate, CsO_2CH	13.1 - 19.2
Zinc Bromide, $ZnBr_2$	15.2 - 20.5
Zinc-Calcium Bromide, $ZnBr_2/CaBr_2$	15.0 - 20.5
Zinc-Calcium Bromide-Chloride, $ZnBr_2/CaBr_2/CaCl_2$	15.0 - 19.2

Density Ranges

There are many fluid options at the lower ranges of density, up to about 10.0 lb/gal. The choice of one brine over another may be based on unique formation properties. Bromide-chloride two salt fluids and formates reach densities up to 13.0 lb/gal. When the density requirement is more than 14.0 lb/gal, your selection is limited to two and three salt halides, zinc bromide ($ZnBr_2$), and cesium formate (CsO_2CH).

FIGURE 4. **Clear Brine Fluid Density Ranges**



Crystallization Temperature

The presence of high concentrations of soluble salts drastically changes the temperature at which, when cooled, crystalline solids begin to form. That temperature is known as the *true crystallization temperature.* For a more in depth discussion of the relationship between salt concentrations and crystallization temperature and factors influencing the measurement of crystallization temperature, see "Crystallization Temperature" on page 181 in Chapter 8 of this guide.

Temperature Considerations

Except for low density single salt fluids, most CBFs are near their crystallization temperature or saturation point with respect to one or more of the dissolved salts. Temperature conditions that are likely to be encountered over the length of the fluid column may cause heating or cooling of the brine. Rapid or unanticipated changes in weather conditions may also cause cooling of a fluid as it travels through surface piping and equipment. It is important to anticipate, as closely as possible, the weather conditions that may occur during the entire course of the completion project.

Critical points in the flow path are:

1. ocean water surface temperature,
2. water temperature at the ocean floor (mudline),
3. atmospheric conditions—temperature changes in surface tankage and distribution piping due to weather,
4. filtration equipment, and
5. pill tanks and storage/transfer tanks.

If the temperature of a completion fluid is allowed to cool below its stated TCT, solid salts will begin to form. The formation of solids will greatly increase demands placed on pumping equipment due to increased resistance to flow. The solids formed may impede filtration two ways—through a cake buildup in the plate and frame diatomaceous earth (DE) filters and/or by plugging cartridges. Additionally, the formation of solids can result in stuck pipe.

⚠ *The loss of soluble salts, either by settling out or filtration, will drastically reduce the density of the completion fluid. Loss of density could result in a dangerous underbalanced situation.*

It is vital to make a temperature profile for the entire flow system expected for the completion fluids. The lowest temperature likely to be encountered will determine the safe crystallization temperature.

☑ *To provide an adequate safety margin, the TCT for the fluid should be set 10°F (5.5°C) below the lowest temperature expected to be encountered at any point along the flow path.*

Seasonal Effects and Brine Selection

Crystallization temperature is controlled by the relative proportions of different brine constituents and is affected by environmental factors. A single salt fluid may work during the heat of the summer, whereas at cooler times of the year, a two salt fluid may be required. In other situations, ambient temperatures may dictate the use of a three salt fluid in the winter months, when a two salt fluid might be all that is necessary in the warmer summer months. An 11.6 blend of calcium bromide ($CaBr_2$) and calcium chloride ($CaCl_2$) has a lower TCT than that of a pure calcium chloride ($CaCl_2$) brine of the same density. Adding water can lower TCT, but doing so will result in a loss of density. Along those same lines, zinc bromide ($ZnBr_2$) can be used to reduce the TCT of a two salt calcium chloride-calcium bromide ($CaCl_2/CaBr_2$) blend, but the introduction of zinc bromide ($ZnBr_2$) will change the nature of the working brine and will impact the environmental regulations regarding conducting disposal activities and reporting and reacting to spills.

Midrange density fluids, 11.7 lb/gal to 15.1 lb/gal, are typical two salt mixtures of calcium chloride ($CaCl_2$) and calcium bromide ($CaBr_2$). The boundary between two and three salt fluids is influenced by seasonal effects and ocean water temperature at depth. Figure 2 on page 11 shows, in a generalized way, the relationship between a brine family and TCT. Values along the vertical axis are density in lb/gal. Colored areas are consistent with those in Figure 3, "TVD-BHP Fluid Density Chart," on page 13.

Pressure Considerations—Pressurized Crystallization Temperature

Deepwater and subsea completions require a greater attention to detail, especially in terms of TCT. At ocean water depths greater than approximately 1,500 feet, an additional adjustment must be made to the fluid formulation. Experience has shown that, at the low temperatures likely to occur in deepwater wells, pressure becomes a factor, and there can be an increase in the measured TCT due to the increase in pressure. At pressures likely to be attained—during the testing of a blowout preventor (BOP) for example—a fluid which functions correctly under normal hydrostatic pressure may begin to crystallize with the increased testing pressure.

TETRA has developed a unique Pressurized Crystallization Temperature (PCT) test designed to measure TCT at various pressures.

☑ *It is strongly recommended that the PCT be determined for fluids where low temperature and high pressure conditions may coexist.*

If you are contemplating a deepwater completion, ask your TETRA representative to have this unique test performed on your fluid.

Temperature and Pressure Effects

When a brine is put into service, the downhole temperature profile will cause the brine to expand, lowering the average density of the fluid column. Pressure has the opposite effect and causes an increase in density. Adjustments will need to be made to the fluid density to compensate for the combination of bottomhole pressure and bottomhole temperature.

For fluids with densities less than approximately 12.0 lb/gal, thermal expansion will typically be in the range of 0.26 lb/gal to 0.38 lb/gal per 100°F (lb/gal/100°F) increase in temperature. From 12.0 lb/gal to 19.0 lb/gal, the expansion ranges from 0.33 lb/gal to 0.53 lb/gal per 100°F increase. Typically, the density correction is made for the average temperature of the fluid column. Pressure effects are much smaller and range from 0.019 lb/gal per thousand psi to 0.024 lb/gal per thousand psi. Table 2 shows some representative values for thermal expansion (A) and hydrostatic compression (B) based on data reported in literature (Bridges, 2000).

TABLE 2. Density Corrections for Temperature and Pressure

Fluid Type	Selected Densities	Thermal Expansion (A)	Hydrostatic Compression (B)
	lb/gal[1]	lb/gal/100°F[1]	lb/gal/1000 psi[1]
NaCl	9.0	0.314	0.0189
NaCl	9.5	0.386	0.0188
NaBr	12.0	0.336	0.0190
$CaCl_2$	9.5	0.285	0.0188
$CaCl_2$	10.0	0.289	0.0187
$CaCl_2$	10.5	0.273	0.0186
$CaCl_2$	11.0	0.264	0.0187
$CaCl_2/CaBr_2$	12.0	0.325	0.0190
$CaCl_2/CaBr_2$	12.5	0.330	0.0193
$CaCl_2/CaBr_2$	13.5	0.343	0.0201
$CaCl_2/CaBr_2$	14.5	0.362	0.0212
$CaCl_2$/Zn-$CaBr_2$	15.5	0.387	0.0226
$CaCl_2$/Zn-$CaBr_2$	16.5	0.416	0.0244
$CaCl_2$/Zn-$CaBr_2$	17.5	0.453	0.0264
$CaCl_2$/Zn-$CaBr_2$	18.0	0.475	0.0276

[1] Values in Table 2 are adapted from data in Bridges (2000), Completion and Workover Fluids, SPE Monograph 19, p 47.

TABLE 2. Density Corrections for Temperature and Pressure

Fluid Type	Selected Densities	Thermal Expansion (A)	Hydrostatic Compression (B)
	lb/gal[1]	lb/gal/100°F[1]	lb/gal/1000 psi[1]
$CaCl_2/Zn\text{-}CaBr_2$	18.5	0.501	0.0288
$CaCl_2/Zn\text{-}CaBr_2$	19.0	0.528	0.0301

[1] Values in Table 2 are adapted from data in Bridges (2000), Completion and Workover Fluids, SPE Monograph 19, p 47.

The fluid density corrected for temperature and pressure (d_c) is calculated using Equation 5 with input values from Equation 3 and Equation 4 and values for A and B from Table 2.

Temperature Correction

EQUATION 3.

$$C_T = \frac{A\,(BHT - surf)}{200}$$

C_T = averaged temperature correction, lb/gal
BHT = bottomhole temperature, °F
surf = surface temperature, °F
A = thermal expansion factor, lb/gal/100°F

Pressure Correction

EQUATION 4.

$$C_P = \frac{B\,(BHP_s)}{2000}$$

C_P = averaged pressure correction, lb/gal
BHP_s = safe bottomhole pressure, psi
B = hydrostatic compression factor, lb/gal/1000 psi

The results of Equation 3 and Equation 4 are used in Equation 5 to obtain the corrected density (d_c).

Corrected Density

EQUATION 5.

$$d_c = d_u + C_T - C_P$$

d_c = density corrected for T and P, lb/gal
d_u = uncorrected density from equation 2, lb/gal
C_T = averaged temperature correction, lb/gal
C_P = averaged pressure correction, lb/gal

The actual corrected density (d_C) of the fluid mixed and delivered to location will be slightly greater than determined, based solely on TVD and BHP in Equation 2 on page 12.

CBF Temperature and Pressure Profile Software (TP-Pro)

A TETRA fluids specialist is equipped to make a more accurate analysis of the temperature, pressure, and density profile for the entire fluid column. Using TETRA's TP-Pro™ program, fluids specialists can analyze the temperature and pressure conditions along the entire length of the flow path to ensure that an accurate and reliable prediction of corrected density is made for your particular application.

TETRA's TP-Pro program calculates the thermal expansion and pressure compressibility behavior of clear brine fluids in a wellbore. The program can be used to model onshore and offshore wells. Solid free brines are especially susceptible to thermal expansion and pressure compressibility, which can significantly alter the effective density of the brine in a downhole application. Because of this susceptibility, a TP-Pro simulation is recommended for every solid free brine application to determine the required surface density of the brine for the necessary effective density.

TABLE 3. **TP-Pro Example of Input Variables**

TP-Pro Input Variables	
Surface Temperature	70°F
Mudline Temperature	39°F
Rig Floor Elevation	82 feet
Water Depth	3,440 feet
Water Depth + Elevation	3,522 feet
Bottomhole Temperature (BHT)	275°F
True Vertical Depth (TVD) of Zone of Interest	17,880 feet
Bottomhole Pressure (BHP)	13,200 psi
Overbalance	250 psi

TABLE 3. TP-Pro Example of Input Variables

TP-Pro Input Variables	
Required Effective Density	14.47 lb/gal
Selected Surface Density	14.60 lb/gal
Pressurized Crystallization Temperature (PCT)	0°F
Fluid Composition (One, Two, or Three Salt)	One Salt
Actual Overbalance	305 psi
Effective Density at 17,880 feet (TVD)	14.53 lb/gal

TABLE 4. TP-Pro Example of Output Variables

Vertical Depth	Actual Density	Effective Density		Temperature
Feet	lb/gal	lb/gal	psi	°F
0	14.60	14.60	0	70
41	14.60	14.60	31	70
82	14.60	14.60	62	70
Water Surface				
770	14.63	14.62	585	64
1,458	14.67	14.63	1,109	58
2,146	14.70	14.65	1,635	51
2,834	14.73	14.66	2,161	45
3,522	14.76	14.68	2,689	39
Mudline				
4,240	14.74	14.69	3,239	51
4,958	14.71	14.70	3,789	63
5,676	14.68	14.70	4,337	74
6,394	14.65	14.69	4,885	86
7,112	14.63	14.69	5,431	98
7,829	14.60	14.68	5,977	110
8,547	14.57	14.67	6,521	122
9,265	14.54	14.66	7,065	133
9,983	14.52	14.65	7,607	145
10,701	14.49	14.64	8,148	157
11,419	14.46	14.63	8,689	169
12,137	14.43	14.62	9,228	181
12,855	14.40	14.61	9,766	192
13,573	14.38	14.60	10,304	204
14,291	14.35	14.59	10,840	216
15,008	14.32	14.57	11,375	228
15,726	14.29	14.56	11,909	240
16,444	14.27	14.55	12,442	251
17,162	14.24	14.54	12,974	263
17,880	14.21	14.53	13,505	275

The results of a TP-Pro simulation are based on best available information and assume equilibrium and static well conditions.

Estimating Required Fluid Volume

Objectives

- Maintain well control—ensure a full column of clear brine fluid of an adequate density
- Respond to pressure changes
- Plan for fluid contingency needs

Factors Affecting

- Well design and surface equipment
- Formation permeability
- Distance to the supply point

Discussion

Carefully estimating the required fluid volume will allow you to maintain an adequate volume of completion fluid to ensure smooth, uninterrupted completion operations.

Determination of the appropriate quantity of completion fluid should be based primarily on the capacity of the casing and tubing used during completion operations. The quantity of fluid circulating at any time is the total of the well volume, less the tubing displacement, plus all surface equipment, piping, pumps, tanks, and filtration equipment. Contingency planning for additional fluid needs will include potential fluid loss and density control. Finally, the distance to the supply point may suggest additional volume to ensure a timely response. As a general rule, the initial fluid order should be at least two to three times the circulating volume of the well.

Calculating Volume Requirements

A volume calculation worksheet should include the following:

1. Circulating volume
2. Holding tanks
3. Filtration equipment
4. Surface piping
5. Contingency needs and pill demands

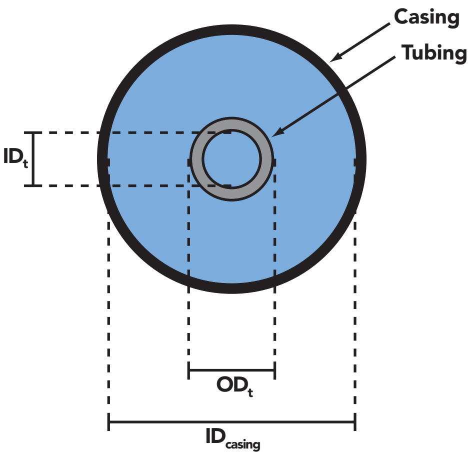
Circulating Volume

Determining the volume of the CBF required to fill the hole and maintain the required hydrostatic pressure is a matter of adding up the casing, liner, and openhole volumes and then subtracting the volume displaced by drill pipe or tubing.

Cased Hole with Tubing. Tables of standard API drill pipe, casing, liners, and tubing are provided in Chapter 6, "Tables, Formulas, and Planning Support." Formulas for pipe volume, annular volume, and velocity are also included in Chapter 6.

Figure 5 is a schematic of the two components of the downhole volume—tubing volume and annular volume. Determining the fluid volume required can be made easy by using the internal capacities for the tubing or working string given in Table 19, "API Tubing — Weight, Dimensions, and Capacities," on page 135 and annular capacities in Table 20, "Annular Capacity," on page 138.

FIGURE 5. Combined Casing and Tubing



Values for combined tubing plus annular capacity in barrels per foot can be calculated using Equation 6. This equation also lends itself to spreadsheet applications for determining capacity.

EQUATION 6.

$$C_{an+t} = \frac{(ID_{casing}^{2} - OD_t^{2} + ID_t^{2})}{1029.4}$$

C_{an+t} = combined annular + tubing capacity, bbl/ft
ID_{casing} = casing ID, in
OD_t = tubing OD, in
ID_t = tubing ID, in
1029.4 = units conversion factor, in^2 -ft/bbl

Holding Tanks

The tank capacity necessary for a CBF job is often substantially greater than that required for circulating a drilling fluid. Since brines are continuously filtered, two holding tanks are required, one for returning fluid that may be carrying solids and another of equal volume for filtered fluid. Holding tank volume may also be limited by rig space.

At least one complete hole volume should be available in surface holding tanks to allow filtration operations to keep pace with circulating requirements.

Filtration Equipment

An allowance should be made for filtration equipment. A larger, high capacity plate and frame filter press with precoat tanks can hold up to 30 barrels of fluid. Table 5 gives some volumes of typical filtration equipment. A typical system will include filter, precoat and body feed tank, guard unit, pumps, and hoses.

TABLE 5. Typical Filtration Equipment Volumes

Equipment	Volume (bbl)	Precoat and Guard[1]	Total
SafeDEflo 600 and C600	5.3	24	29.3
SafeDEflo 1100	7.1	24	31.1
SafeDEflo 1300	8.4	24	32.4
SafeDEflo 1500	9.6	24	33.6

[1] Precoat and Body Feed Tanks = 20 bbl and Guard Unit = 4 bbl

Surface Piping

Any unusual requirements for positioning equipment can result in additional volumes in hoses, pumps, and piping. An allowance of 10 barrels is a reasonable recommendation.

Contingency Planning and Pill Demands

Fluid Loss Pills. On occasion, it may become necessary to pump a viscous pill into the producing zone to slow fluid loss. The volume of the pill will be equal to at least the combined annular and tubing volume through the perforated zone plus some additional footage for safety. As a rule of thumb, about 1.5 times the volume of the perforated zone can be used.

Spike Material. Spike material, or spike fluid, is high density fluid that is transported to and stored on location in case it is necessary to raise fluid density in order to control pressure or respond to a kick. The volume usually ranges between 75 and 150 bbl of a selected high density blending stock. The volume of spike material that is held in reserve should be based on a number of factors, including:

- uncertainty regarding bottomhole pressure,
- treating dilutions of working fluid,
- available storage space on the location or rig,
- density difference between the working fluid and the spike fluid,
- environmental discharge/spill limitations, and
- cost considerations.

A detail that is often overlooked when determining the density and volume of spike material is the relative amount of spike fluid needed to raise the density of the working fluid by a particular increment. Often, it is more economical to use a much heavier spike fluid, even if its unit cost is higher. The reason for this is that it may take substantially less of the heavier spike material to obtain the same density increase. An illustration of this relationship is shown in Figure 6.

For example, it will take twice as much 19.2 lb/gal zinc/calcium bromide ($ZnBr_2$/$CaBr_2$) to raise the density of a 17.8 lb/gal working fluid by 0.2 lb/gal than it would if a 20.5 lb/gal $ZnBr_2$ spike fluid was used. Half the volume of 20.5 lb/gal fluid could be transported and stored as spike fluid. In addition to the smaller storage needs of the higher density spike fluid, there is the added benefit that, when it is used to achieve a given density adjustment, it will create a smaller volume increase in the working fluid.

FIGURE 6. Selecting and Using Spike Fluids

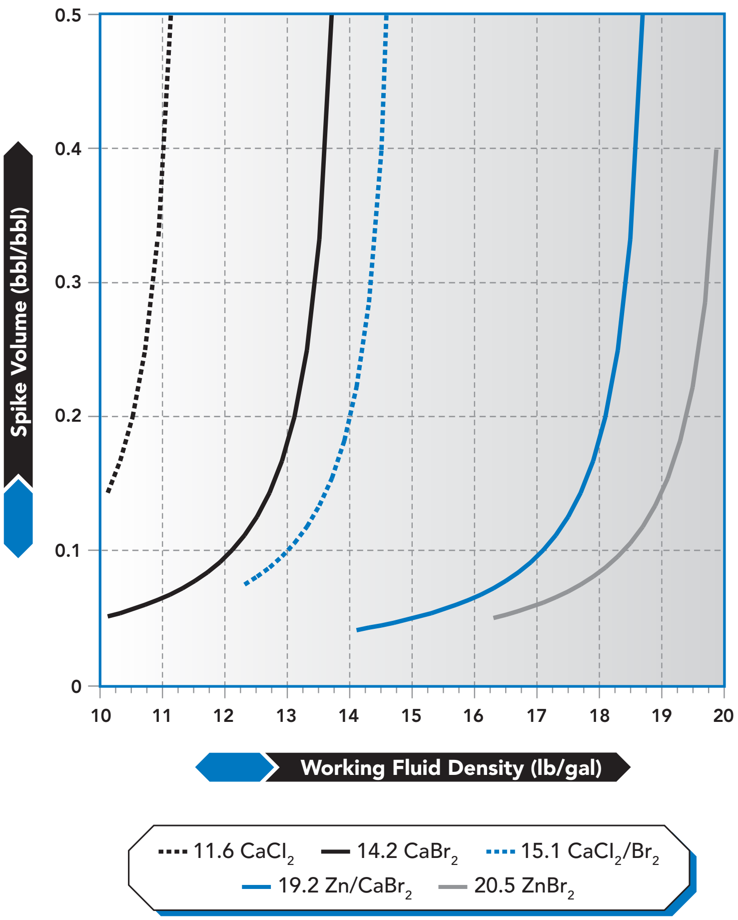


Figure 6 shows the amount of spike fluid, in fractions of a barrel, it takes to raise the density of one barrel of any working fluid by an adjustment of 0.2 lb/gal. To use this guide, choose a density of working fluid along the bottom and lay a straight edge vertically through the chart to find the relative volume of fluid needed to make a 0.2 lb/gal adjustment.

Permeability and Pressure Conditions in a Producing Zone

Formation characteristics will play a large role in determining the amount of fluid that is held in reserve. Large quantities of fluid may be lost to highly permeable formations or formations that contain fracture permeability. Experience in a particular producing horizon may dictate carrying extra fluid inventory to allow for seepage into the formation.

Distance to the Supply Point

The distance to the nearest supply point, uncertainty about bottomhole conditions, and seasonal factors such as temperature changes should be considered in determining the volume delivered at the beginning of the job. Deepwater offshore platforms will probably have longer supply lead times than shallow water or onshore projects. In cases where substantial delays could impact operations, additional volume should be purchased to ensure that volume losses can be made up on a safe and timely basis in order to avoid delays.

Volume Calculation Worksheet

According to the general rule, the initial fluid order should be two to three times the circulating volume of the well. Another method for determining the initial fluid quantity is to use a tool similar to the volume calculation worksheet below.

Volume Calculation Worksheet

Equipment	Volume
Circulating Volume	
Holding Tanks	
Filtration Equipment	
Surface Piping	
Contingency Needs	
Total	

Fluid Compatibility

Mineralogy

Reservoir mineralogy, especially the percentage and type of clays that will be encountered, may influence your decision as to the type of CBF best suited to a particular formation. The dominant cation (positively charged ion) in the brine, for example, ammonium (NH_4^+), sodium (Na^+), potassium (K^+), calcium (Ca^{+2}), or zinc (Zn^{+2}), will react with clay minerals to promote stability or act as a dispersant. Compatibility testing of core samples from the reservoir is the most reliable means of assessing the response of clay minerals to a brine. Experience in offset wells should also be considered if existing data indicates sensitivity of clay minerals.

Contact a TETRA fluids specialist to arrange for brine compatibility testing.

Reservoir Fluid Chemistry

Reservoir fluids are in a state of chemical equilibrium with the reservoir minerals. This state of equilibrium will be disturbed once a formation is penetrated and production activities begin. Prior to producing the well, the potential for formation damage resulting from reactions between formation fluids and drilling or completion fluids will exist. The chemical composition of formation waters should be evaluated for compatibility, paying attention to the degree of saturation with salt (NaCl) and any bicarbonate and sulfate ion concentrations.

Metallurgy and Elastomers

Clear brine fluids must also be compatible with the materials used in downhole equipment and with any tools with which they will come into contact. Temperature, pressure, and mechanical stresses can result in corrosion induced by the interaction between clear brine fluids and various types of metals. The increase in HPHT drilling has led to greater use of corrosion resistant alloys (CRAs) in production tubing. The incidence of catastrophic tubing failure due to environmentally assisted cracking (EAC) has risen with the increased use of CRAs. Because of these failures, compatibility of completion and packer fluids with CRA tubing has become a critical consideration, especially when planning HPHT wells. To provide empirical data to support its customers, TETRA has participated in extensive research aimed at understanding the causes of EAC and the steps that can be taken to decrease the probability of its occurrence. TETRA fluids specialists can provide technical guidance in the proper design of a clear brine fluid system.

Chemically and mechanically induced interactions should be assessed by TETRA's fluids experts. If you are planning a well completion where a CRA will be used, ask for a customer recommendation report from the MatchWell fluid compatibility selector.

Specialty Formulated Brines and Engineered Fluid Systems

There are occasions when you may suspect compatibility issues or return permeability problems. These exceptional conditions may require an engineered fluid system approach involving TETRA's specialty brine blending, a MatchWell recommended fluid, or a nonconventional fluid.

When your data suggests that out of the ordinary conditions may exist in a well or producing zone, it is best to obtain the advice of your TETRA fluids specialist and TETRA technical service professional who can help you explore alternatives. Because these are unique situations, each one should be investigated and recommendations should be developed on the basis of available test data.

Some of the conditions that may arise and require unique approaches to completion fluids may include:

1. density range, bottomhole temperature, and pressure conditions,
2. dispersible or water sensitive clay minerals,
3. metallurgical considerations such as high chromium alloys, and
4. compatibility problems between formation fluids and the completion fluid.

Reasons to Consider a Specialty Fluid

When making a fluid selection, there are many things you need to consider. Table 6 gives a relative weighing of some of the considerations that will enter into a decision to use one type of specialty fluid over another. The decision will usually be based on one primary criterion and others will be weighed to a lesser degree. If a fluid has a distinct advantage in a particular category over other fluids in the same density range, a plus sign (+) is shown in that column. An equal sign (=) indicates no distinct advantage over fluids in the density range. Finally, a minus sign (–) indicates that a fluid has a disadvantage over other fluids in that particular density range.

TABLE 6. Specialty Brine Considerations

Brine	Shale/ Clay	Acid Corrosion	Carbonate	Sulfate
Ammonium Chloride (NH_4Cl)	+	−	+	+
Potassium Chloride (KCl)	+	=	+	+
Sodium Chloride (NaCl)	−	=	+	+
Sodium Bromide (NaBr)	−	=	+	+
Sodium Formate (NaO_2CH)	=	+	+	+
Potassium Formate (KO_2CH)	+	+	+	+
Calcium Chloride ($CaCl_2$)	+	=	−	−
Calcium Bromide ($CaBr_2$)	+	=	−	−
Cesium Formate (CsO_2CH)	=	+	+	+
Zinc Bromide ($ZnBr_2$)	+	−	=	+

+ advantage
= parity to other options
– disadvantage

Shale/Clay Dispersion

Many clay minerals will swell and can potentially disperse when exposed to the sodium ion (Na^+). In general, fluids containing potassium (K^+) and ammonium (NH_4^+) ions have a tendency to stabilize clay minerals by adsorbing into the clay structure. Divalent ions such as calcium (Ca^{+2}) and zinc (Zn^{+2}) also strongly adsorb into many clay minerals and create a nondamaging environment in the vicinity of the wellbore.

Acid Corrosion

Corrosion of metallic surfaces that come into contact with brines is strongly accelerated by the presence of the hydrogen ion (H^+). The hydrogen ion can be essentially eliminated by raising the pH of a brine. The pH of fluids containing sodium, potassium, or calcium can be raised into a range where only negligible concentrations of hydrogen ions are present. Adjusting the pH of fluids containing ammonium or zinc ions is not recommended, as those ions are not stable at the pH levels that can be attained in other CBFs.

Carbonate

Formation waters are in a state of chemical equilibrium with formation minerals. Certain calcareous reservoirs with a high partial pressure of carbon dioxide may be incompatible with fluids that contain the calcium ion. Mixing formation water and calcium containing CBFs may result in the precipitation of calcium carbonate at the point of contact between the two fluids. The formation of calcium carbonate can result in permeability reduction, which is difficult to reverse even with strong acid stimulation.

If formation water analysis indicates high levels of the bicarbonate ion (HCO_3^{+1}), fluids containing calcium should be avoided.

Sulfate

If formation water contains the sulfate ion (SO_4^{-2}) at a concentration of more than 500 ppm, it will react with the calcium ion to form a precipitate that will not readily respond to acid stimulation. Analysis of formation water will provide the only reliable means to assess the potential for this type of formation damage.

Of additional concern, the sulfate ion may also be converted to H_2S by sulfate reducing bacteria. If this conversion occurs, the associated health and corrosion issues will have to be addressed.

The Next Steps

The information outlined in the preceding sections has explained the first stages of completion fluid planning. At this point, the general brine family, density (corrected for temperature and pressure), crystallization point, metallurgy, and volume of fluid required for the job have been determined. The following chapter goes through the processes and systems associated with a CBF job. Information is arranged by system.

Notes:

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