CHEMICAL AND PHYSICAL PROPERTIES

SECTION A4
VISCOSITY OF FORMATE BRINES

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CABOT

VERSION 3 – 03/14

A4.1 Introduction

Viscosity is a fluid property defined as the 'fluid's resistance to flow'. In everyday terms, viscosity is typically referred to as 'thickness' or 'internal friction'. Water has very low viscosity. An example of fluid with high viscosity is honey.

For well construction fluids it is desirable to use a base fluid with the lowest possible viscosity and then build the desired rheological profile by adding appropriate rheology modifiers, such as polymers. Drilling fluids, for example, should be 'shear thinning', which means they are 'thin' when circulating to avoid high frictional pressure losses and 'thick' when static to suspend solids. If a viscous base fluid is used, it is impossible to formulate highly shear-thinning fluids.

Brines are generally Newtonian fluids, which means viscosity remains the same whether they are exposed to high or low shear. In scientific terms, this means that shear stress is proportional to shear rate, or that shear stress versus shear (or strain) rate curve is linear. Brines generally have low viscosity when their salt (solute) content is low, but this can increase exponentially when they approach salt saturation.

Formate brines' viscosity is quite low over a wide density range and they deliver exceptional hydraulic efficiency in well construction operations. The viscosity of fluids based on formate brines can be modified by the addition of water-soluble rheology modifiers (viscosifiers). Formate brines, as opposed to conventional high-density brines containing divalent cations, are fully compatible with commonly used drilling fluid viscosifiers, such as xanthan gum (see Section B5 Compatibility with Additives).

A4.2 Viscosity of single-salt formate brines as a function of brine density and temperature

Viscosities for single-salt sodium formate, potassium formate, and cesium formate brines as a function of temperature and density have been measured by Cabot Operations and Technical Support Laboratory in Aberdeen using a HAAKE MARS III Rheometer with a DG41 DIN 53544 double-gap cylinder sensor system [1]. The measured viscosities have been surface fitted in a 3D model using TableCurve 3D 4.0 software to predict viscosity as a function of density and temperature. The brines used for testing are cesium formate field-grade brine from Cabot's mine in Canada, potassium formate field-grade brine from EsterChem, and sodium formate field-grade powder from an unknown source. Pure, analytical grade products are expected to give slightly lower viscosity.

Figure 1 shows the viscosity of sodium formate, potassium formate, and cesium formate single-salt brines as a function of brine density at 25°C / 77°F. As can be seen, all three formate brines have relatively low viscosity. Of the three brines, potassium formate has the highest viscosity at saturated conditions, whilst cesium formate has the lowest. Cesium formate is unique as its viscosity remains low even when approaching crystallization point.

Viscosity as a function of density and temperature for the three formate brines is found in the following tables and figures:

Sodium formate single-salt brine

Table 1	Viscosity as a function of temperature and density
Figure 2	Viscosity as a function of density for a range of temperatures
Figure 3	Viscosity as a function of temperature for a range of densities

Potassium formate single-salt brine

Table 2	Viscosity as a function of temperature and density
Figure 4	Viscosity as a function of density for a range of temperatures
Figure 5	Viscosity as a function of temperature for a range of densities

Cesium formate single-salt brine

Table 3	Viscosity as a function of temperature and density
Figure 6	Viscosity as a function of density for a range of temperatures
Figure 7	Viscosity as a function of temperature for a range of densities

As seen in Figures 3, 5, and 7 all three formate brines are temperature-thinning. Under typical downhole temperature conditions, all formate brines have very low viscosities from 1 – 5 cP. Viscosities are only measured up to 100°C / 212°F. However, as seen in the figures, temperature dependence is not as significant at these higher temperatures, and good viscosity estimates are made by extrapolating the curves.

A4.3 Viscosity of blended formate brines as a function of brine density and temperature

The HAAKE MARS III viscometer has also been used to measure viscosity of blended cesium / potassium formate brines. A 2.20 g/cm^3 / 18.36 lb/gal cesium formate brine and a 1.57 g/cm^3 / 13.10 lb/gal potassium formate brine were blended at several ratios to give a range of brine densities. Viscosity was measured for all blended brines at temperatures between 0°C / 32°F and 100°C / 212°F and a very close to linear relationship between viscosity and blend ratio was estabilised. Table 4 and Figure 8 show viscosity as a function of brine density and temperature for blends of 2.20 g/cm^3 / 18.36 lb/gal cesium formate field brine and 1.57 g/cm^3 / 13.1 lb/gal potassium formate field brine, which are typical stock brines. Please keep in mind that these figures are only included as guidance. Blended cesium / potassium formate brines from Cabot are not always strict blends of these two stock brines. For this reason, it is always best to measure brine viscosity using an identical composition to the one planned for field use.

A4.4 Effect of pressure on viscosity of formate brines

Formate brines have low compressibility. Pressure is therefore not expected to greatly influence formate brine viscosity, although experimental data are scarce. The only measurements currently available are from standard-stock cesium formate brine with density of 2.2 g/cm^3 / 18.3 lb/gal. The viscosity measurements were performed at three different temperatures using a capillary tube viscometer operated by Westport Technology Center International. At all temperatures, viscosity shows a linear relationship with pressure. The increase in viscosity with pressure is estimated to be approximately:

0.36 cP per 10,000 psi @ 38°C / 100°F

0.21 cP per 10,000 psi @ 66°C / 150°F

0.16 cP per 10,000 psi @ 93°C / 200°F

These results indicate that pressure does not appear to greatly influence formate brines' viscosity in comparison with the effect of brine composition and temperature. Pressure dependence is not available for viscosities of blended cesium and potassium formate brines. However, measurements are currently being carried out at Cabot Operations and Technical Support Laboratory, Aberdeen, and will be available shortly. One can, however, assume that these blended brines will behave much like pure cesium formate brine when pressurized.

A4.5 Fann 35 viscosity data for formate brines

Formate brines are Newtonian fluids, which means:

- Shear stress is proportional to shear rate
- Viscosity is the same for all shear rates

A Fann 35 viscometer is designed to measure non-Newtonian viscosity, i.e. shear stress at a variety of shear rates. In a Newtonian fluid, such as formate brines, there is a fixed relationship between applied shear rate and measured shear stress. It is therefore sufficient to measure shear stress at one shear rate.

Some simulation models, however, require viscosity readings from a Fann 35 viscometer. Fann 35 rheology can be calculated from Newtonian viscosity by using the following equation:

$$nN = S \times D \times f \times C \quad (1)$$

Where

S = Speed factor
D = Fann 35 dial reading [lbs/100ft^2]
f = Spring factor
C = Rotor-bob factor
nN = Newtonian viscosity [cP]

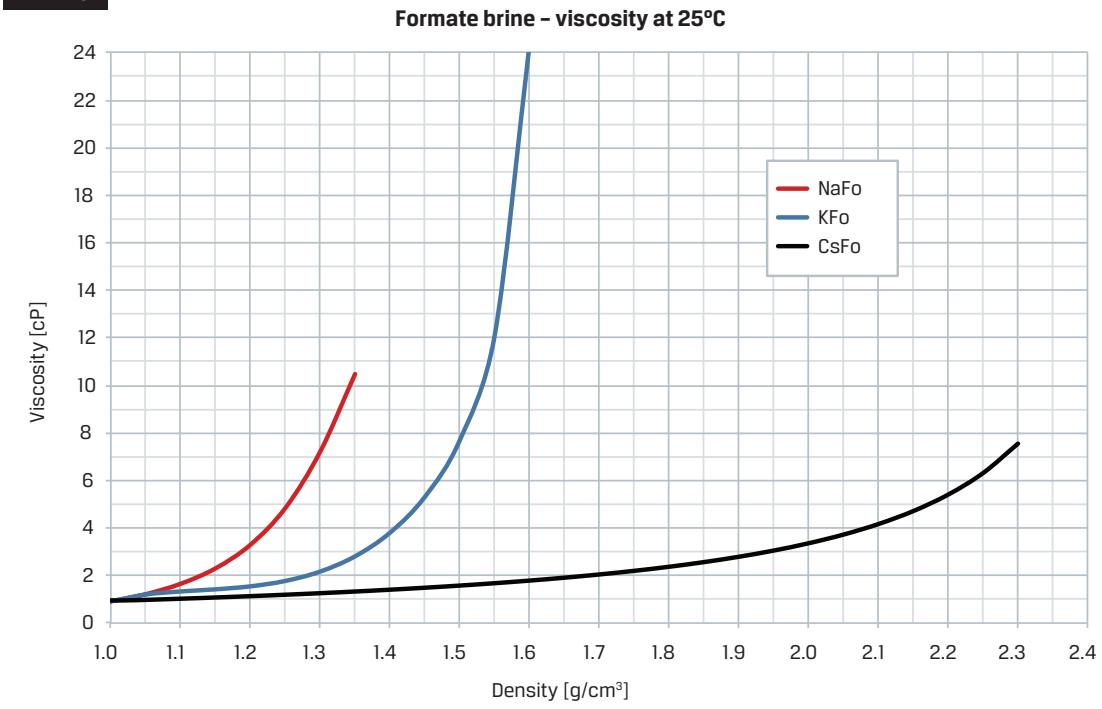
When the Fann 35 rheometer is run with a standard R1-B1-F1 combination, using Equation 1 above, the following relationships apply between viscosity in centipoises [cP] (reported in sections A4.2 and A4.3 above) and standard Fann 35 dial readings (D):

Fann speed [rpm]	**Fann 35 dial reading**
3	$D = nN/100$
6	$D = nN/50$
100	$D = nN/3$
200	$D = nN/1.5$
300	$D = nN$
600	$D = nN \times 2$

References

[1] "Measuring Viscosities of Formate Brines using HAAKE MARS III Rheometer", laboratory report number LR-607, Cabot Operations and Technical Support Laboratory, Aberdeen, October 2012.

METRIC



FIELD

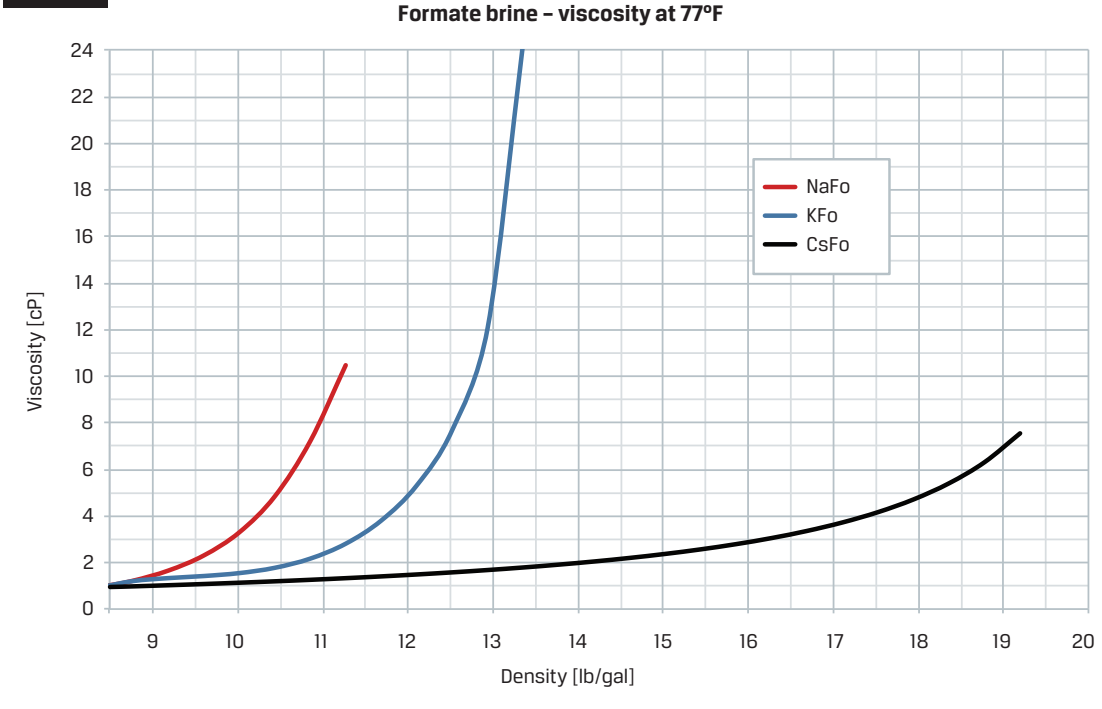


Figure 1 Viscosity of typical field-grade sodium, potassium, and cesium formate brine as a function of brine density at 25°C / 77°F.

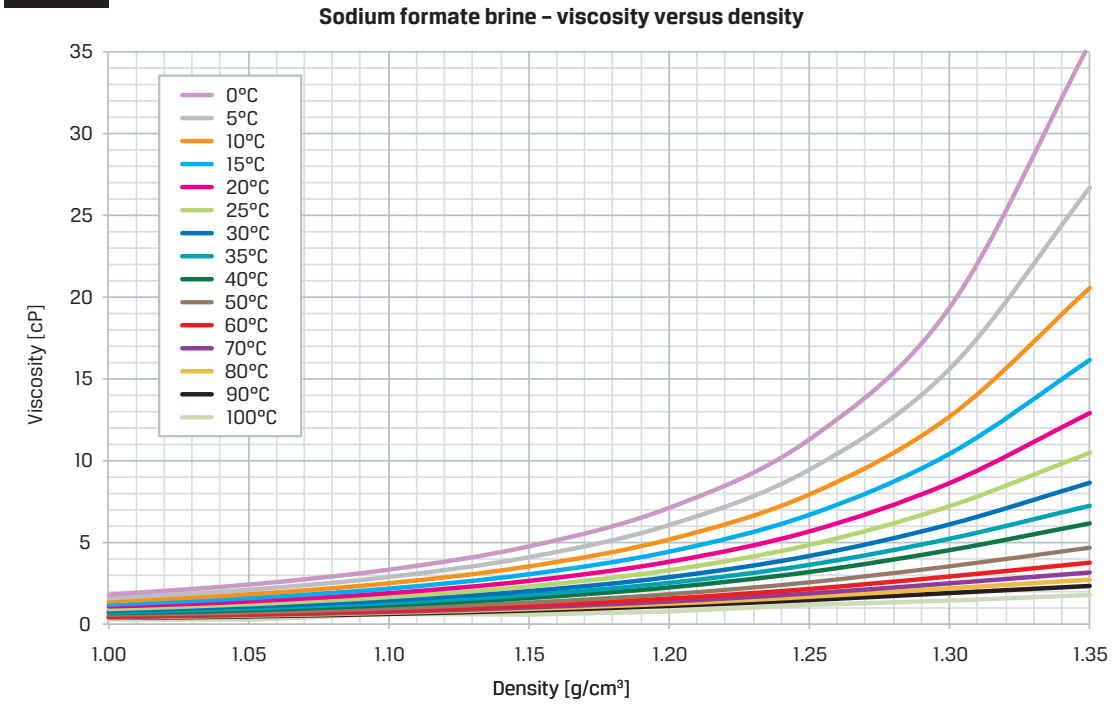
Table 1 Viscosity of field-grade sodium formate brine as a function of density and temperature in metric units.

METRIC																			
Viscosity [cP]	**0°C**	**5°C**	**10°C**	**15°C**	**20°C**	**25°C**	**30°C**	**35°C**	**40°C**	**45°C**	**50°C**	**55°C**	**60°C**	**65°C**	**70°C**	**75°C**	**80°C**	**90°C**	**100°C**
1.05 g/cm³	2.4	2.1	1.8	1.6	1.4	1.2	1.1	1.0	0.9	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4
1.10 g/cm³	3.3	2.9	2.5	2.2	1.9	1.7	1.5	1.3	1.2	1.0	1.0	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.5
1.15 g/cm³	4.7	4.1	3.5	3.0	2.6	2.3	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.8	0.7
1.20 g/cm³	7.1	6.1	5.2	4.4	3.8	3.3	2.9	2.5	2.2	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	0.9
1.25 g/cm³	11	9.4	7.9	6.7	5.7	4.8	4.2	3.6	3.2	2.8	2.6	2.3	2.1	2.0	1.9	1.8	1.7	1.5	1.2
1.30 g/cm³	19	16	13	10	8.6	7.2	6.1	5.2	4.5	4.0	3.5	3.2	2.9	2.7	2.5	2.3	2.2	1.9	1.6
1.35 g/cm³	36	27	21	16	13	10	8.6	7.2	6.2	5.3	4.7	4.2	3.8	3.4	3.2	2.9	2.7	2.3	1.9

Table 2 Viscosity of field-grade sodium formate brine as a function of density and temperature in field units.

FIELD																			
Viscosity [cP]	**30°F**	**40°F**	**50°F**	**60°F**	**70°F**	**80°F**	**90°F**	**100°F**	**110°F**	**120°F**	**130°F**	**140°F**	**150°F**	**160°F**	**170°F**	**180°F**	**190°F**	**200°F**	**210°F**
8.6 lb/gal	2.7	2.2	1.7	1.4	1.2	1.0	0.85	0.72	0.63	0.54	0.48	0.42	0.37	0.33	0.29	0.26	0.23	0.21	0.19
8.8 lb/gal	3.1	2.4	2.0	1.6	1.3	1.1	0.95	0.81	0.70	0.61	0.53	0.47	0.41	0.37	0.33	0.29	0.26	0.23	0.21
9.0 lb/gal	3.5	2.8	2.2	1.8	1.5	1.3	1.1	0.92	0.79	0.69	0.60	0.53	0.47	0.41	0.37	0.33	0.29	0.26	0.24
9.2 lb/gal	4.0	3.1	2.5	2.1	1.7	1.4	1.2	1.0	0.90	0.78	0.69	0.60	0.53	0.47	0.42	0.37	0.34	0.30	0.27
9.4 lb/gal	4.6	3.6	2.9	2.4	2.0	1.7	1.4	1.2	1.0	0.91	0.79	0.70	0.61	0.54	0.48	0.43	0.39	0.35	0.31
9.6 lb/gal	5.4	4.2	3.4	2.8	2.3	1.9	1.6	1.4	1.2	1.1	0.92	0.81	0.72	0.64	0.56	0.50	0.45	0.40	0.36
9.8 lb/gal	6.4	5.0	4.1	3.3	2.7	2.3	2.0	1.7	1.4	1.3	1.1	1.0	0.85	0.75	0.67	0.60	0.53	0.48	0.43
10.0 lb/gal	7.7	6.1	4.9	4.0	3.3	2.8	2.4	2.0	1.7	1.5	1.3	1.2	1.0	0.90	0.80	0.71	0.64	0.57	0.51
10.2 lb/gal	9.4	7.4	6.0	4.9	4.0	3.4	2.9	2.5	2.1	1.8	1.6	1.4	1.2	1.1	1.0	0.87	0.78	0.70	0.62
10.4 lb/gal	11.6	9.2	7.4	6.0	5.0	4.2	3.6	3.0	2.6	2.3	2.0	1.7	1.5	1.4	1.2	1.1	1.0	0.86	0.77
10.6 lb/gal	14.6	11.5	9.3	7.6	6.3	5.3	4.5	3.8	3.3	2.9	2.5	2.2	1.9	1.7	1.5	1.4	1.2	1.1	1.0
10.8 lb/gal	18.4	14.5	11.7	9.6	7.9	6.6	5.6	4.8	4.2	3.6	3.1	2.8	2.4	2.2	1.9	1.7	1.5	1.4	1.2
11.0 lb/gal	22.9	18.1	14.6	11.9	9.9	8.3	7.0	6.0	5.2	4.5	3.9	3.4	3.0	2.7	2.4	2.1	1.9	1.7	1.5
11.2 lb/gal	29.5	23.3	18.8	15.3	12.7	10.7	9.0	7.7	6.7	5.8	5.0	4.4	3.9	3.5	3.1	2.7	2.4	2.2	1.9

METRIC



FIELD

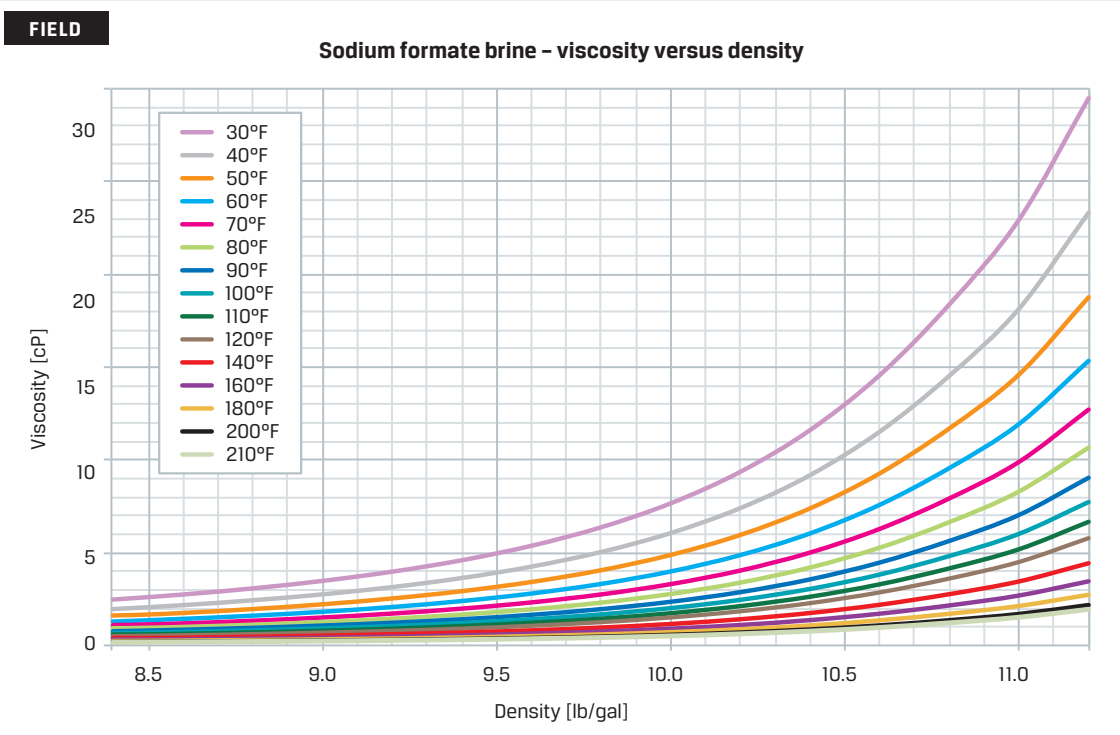
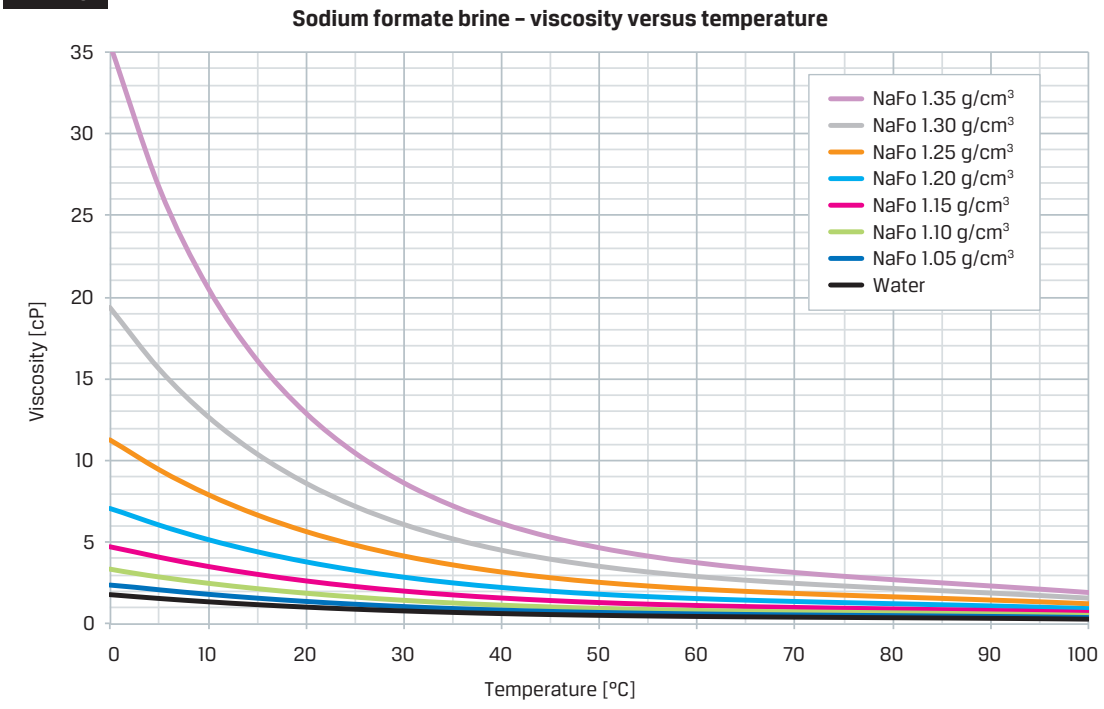


Figure 2 Viscosity of field-grade sodium formate as a function of density under various temperature conditions.

METRIC



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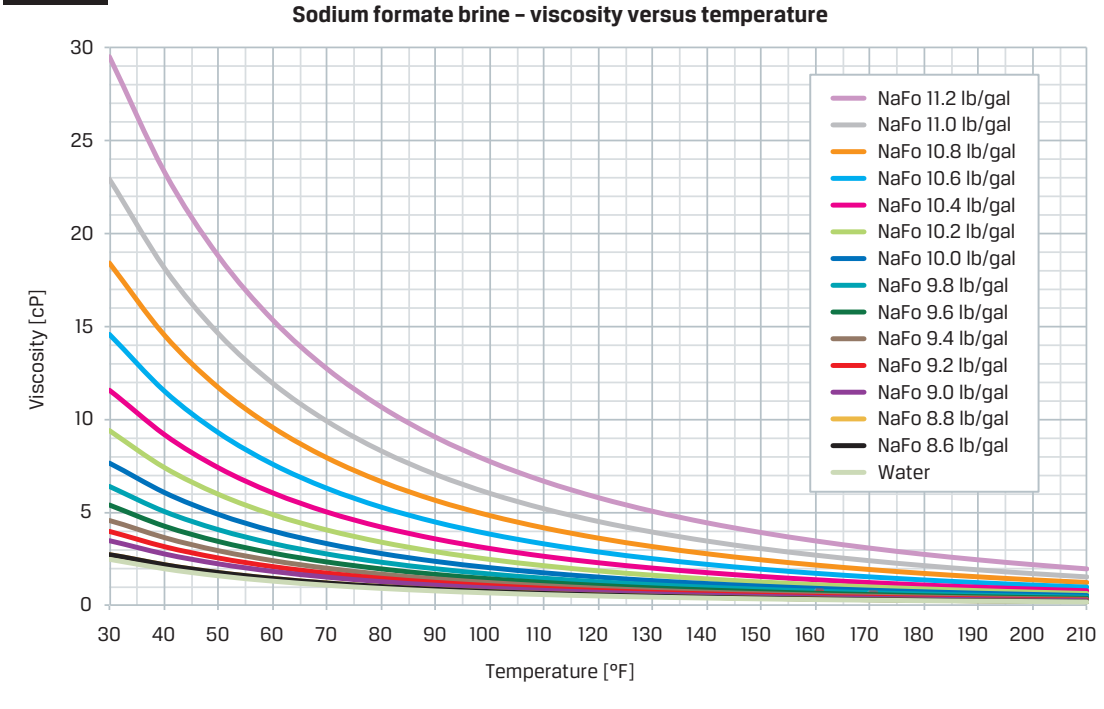


Figure 3 Viscosity of field-grade sodium formate brine with various densities as a function of temperature.

Table 3 Viscosity of field-grade potassium formate brine as a function of density and temperature in metric units.

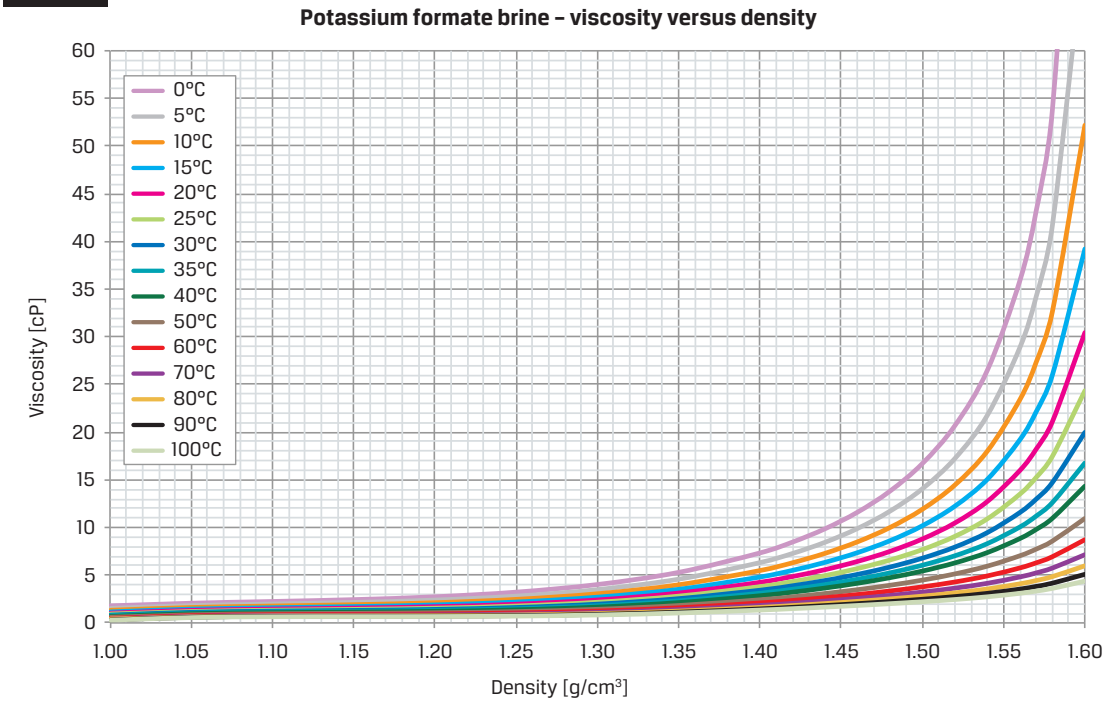
METRIC

Viscosity [cP]	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C	45°C	50°C	55°C	60°C	65°C	70°C	75°C	80°C	90°C	100°C
1.05 g/cm³	2.1	1.8	1.6	1.4	1.3	1.2	1.1	1.0	1.0	0.90	0.85	0.80	0.76	0.72	0.69	0.66	0.63	0.59	0.56
1.10 g/cm³	2.2	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.91	0.86	0.82	0.79	0.75	0.73	0.68	0.65
1.15 g/cm³	2.4	2.1	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.1	1.0	0.95	0.90	0.86	0.82	0.78	0.75	0.70	0.66
1.20 g/cm³	2.7	2.4	2.1	1.9	1.7	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.89	0.85	0.81	0.77	0.71	0.67
1.25 g/cm³	3.2	2.8	2.5	2.2	2.0	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.0	1.0	0.93	0.88	0.83	0.76	0.71
1.30 g/cm³	4.0	3.5	3.1	2.7	2.4	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.89	0.83
1.35 g/cm³	5.3	4.6	4.0	3.5	3.1	2.8	2.5	2.3	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0
1.40 g/cm³	7.3	6.3	5.5	4.8	4.3	3.8	3.4	3.1	2.8	2.6	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.3
1.42 g/cm³	8.5	7.3	6.3	5.5	4.9	4.3	3.9	3.5	3.2	3.0	2.7	2.5	2.4	2.2	2.1	1.9	1.8	1.6	1.5
1.44 g/cm³	9.9	8.4	7.3	6.3	5.6	5.0	4.4	4.0	3.7	3.3	3.1	2.8	2.6	2.5	2.3	2.2	2.0	1.8	1.7
1.46 g/cm³	12	9.9	8.5	7.4	6.4	5.7	5.1	4.6	4.2	3.8	3.5	3.2	3.0	2.8	2.6	2.4	2.3	2.0	1.8
1.48 g/cm³	14	12	10	8.6	7.5	6.6	5.9	5.2	4.7	4.3	3.9	3.6	3.3	3.1	2.9	2.7	2.5	2.2	2.0
1.50 g/cm³	17	14	12	10	8.8	7.7	6.8	6.0	5.4	4.9	4.5	4.1	3.8	3.5	3.2	3.0	2.8	2.5	2.2
1.52 g/cm³	21	17	15	12	11	9.1	8.0	7.0	6.3	5.7	5.1	4.7	4.3	3.9	3.6	3.4	3.1	2.8	2.5
1.54 g/cm³	27	22	18	15	13	11	9.5	8.3	7.4	6.6	6.0	5.4	4.9	4.5	4.2	3.8	3.6	3.1	2.7
1.56 g/cm³	36	29	23	19	16	14	12	10	8.8	7.9	7.0	6.4	5.8	5.3	4.8	4.4	4.1	3.5	3.1
1.57 g/cm³	43	34	27	22	18	15	13	11	9.8	8.7	7.7	7.0	6.3	5.7	5.2	4.8	4.4	3.8	3.3
1.58 g/cm³	54	42	33	26	21	18	15	13	11	9.7	8.6	7.7	6.9	6.3	5.8	5.3	4.9	4.2	3.6
1.60 g/cm³	102	72	52	39	30	24	20	17	14	12	11	9.7	8.7	7.9	7.2	6.5	6.0	5.1	4.4

Table 4 Viscosity of field-grade potassium formate brine as a function of density and temperature in field units.

FIELD																			
Viscosity [cP]	**30°F**	**40°F**	**50°F**	**60°F**	**70°F**	**80°F**	**90°F**	**100°F**	**110°F**	**120°F**	**130°F**	**140°F**	**150°F**	**160°F**	**170°F**	**180°F**	**190°F**	**200°F**	**210°F**
8.6 lb/gal	2.0	1.8	1.5	1.3	1.2	1.1	1.0	0.91	0.84	0.78	0.73	0.68	0.64	0.60	0.57	0.55	0.52	0.50	0.49
8.8 lb/gal	2.1	1.9	1.6	1.4	1.3	1.2	1.1	1.0	0.94	0.88	0.82	0.78	0.73	0.70	0.66	0.64	0.61	0.59	0.58
9.0 lb/gal	2.2	1.9	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.88	0.83	0.79	0.75	0.72	0.69	0.66	0.64	0.63
9.2 lb/gal	2.3	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.0	1.0	0.92	0.87	0.82	0.78	0.75	0.72	0.69	0.67	0.65
9.4 lb/gal	2.4	2.1	1.8	1.6	1.5	1.3	1.2	1.1	1.1	1.0	0.94	0.89	0.84	0.80	0.76	0.73	0.70	0.68	0.66
9.6 lb/gal	2.5	2.2	1.9	1.7	1.5	1.4	1.3	1.2	1.1	1.0	1.0	0.90	0.85	0.81	0.77	0.74	0.71	0.68	0.67
9.8 lb/gal	2.6	2.3	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.0	1.0	0.92	0.86	0.82	0.78	0.74	0.71	0.69	0.67
10.0 lb/gal	2.8	2.4	2.1	1.9	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.94	0.89	0.84	0.79	0.75	0.72	0.69	0.67
10.2 lb/gal	3.0	2.6	2.2	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.0	1.0	0.92	0.86	0.82	0.77	0.74	0.71	0.69
10.4 lb/gal	3.3	2.8	2.4	2.1	1.9	1.7	1.5	1.4	1.3	1.2	1.1	1.0	1.0	0.91	0.85	0.81	0.77	0.74	0.71
10.6 lb/gal	3.6	3.1	2.7	2.3	2.1	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	1.0	0.91	0.86	0.82	0.79	0.76
10.8 lb/gal	4.0	3.4	3.0	2.6	2.3	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.89	0.85	0.82
11.0 lb/gal	4.6	3.9	3.3	2.9	2.6	2.3	2.1	1.9	1.7	1.6	1.5	1.3	1.3	1.2	1.1	1.0	1.0	0.94	0.90
11.2 lb/gal	5.2	4.4	3.8	3.3	2.9	2.6	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0
11.4 lb/gal	6.0	5.1	4.4	3.8	3.4	3.0	2.7	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
11.6 lb/gal	7.1	6.0	5.1	4.4	3.9	3.4	3.1	2.8	2.5	2.3	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3
11.8 lb/gal	8.4	7.1	6.0	5.2	4.5	4.0	3.6	3.2	2.9	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.6	1.5	1.5
12.0 lb/gal	10	8.5	7.2	6.2	5.4	4.7	4.2	3.8	3.4	3.1	2.8	2.6	2.4	2.2	2.1	2.0	1.8	1.7	1.7
12.2 lb/gal	12	10	8.6	7.4	6.4	5.6	4.9	4.4	4.0	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.1	2.0	1.9
12.4 lb/gal	15	13	11	8.9	7.6	6.6	5.8	5.2	4.6	4.2	3.8	3.5	3.2	2.9	2.7	2.5	2.4	2.2	2.1
12.6 lb/gal	19	16	13	11	9.3	8.0	6.9	6.1	5.4	4.9	4.4	4.0	3.7	3.4	3.1	2.9	2.7	2.5	2.4
12.8 lb/gal	25	21	17	14	12	9.8	8.4	7.4	6.5	5.8	5.2	4.7	4.3	3.9	3.6	3.3	3.1	2.9	2.7
13.0 lb/gal	36	29	23	18	15	12	11	9.1	8.0	7.1	6.3	5.7	5.1	4.6	4.2	3.9	3.6	3.3	3.1
13.1 lb/gal	45	35	27	22	17	14	12	10	9.0	7.9	7.0	6.3	5.7	5.1	4.7	4.3	3.9	3.6	3.4
13.2 lb/gal	60	45	34	26	21	17	14	12	10	9.0	7.9	7.1	6.3	5.7	5.2	4.8	4.4	4.0	3.7

METRIC



FIELD

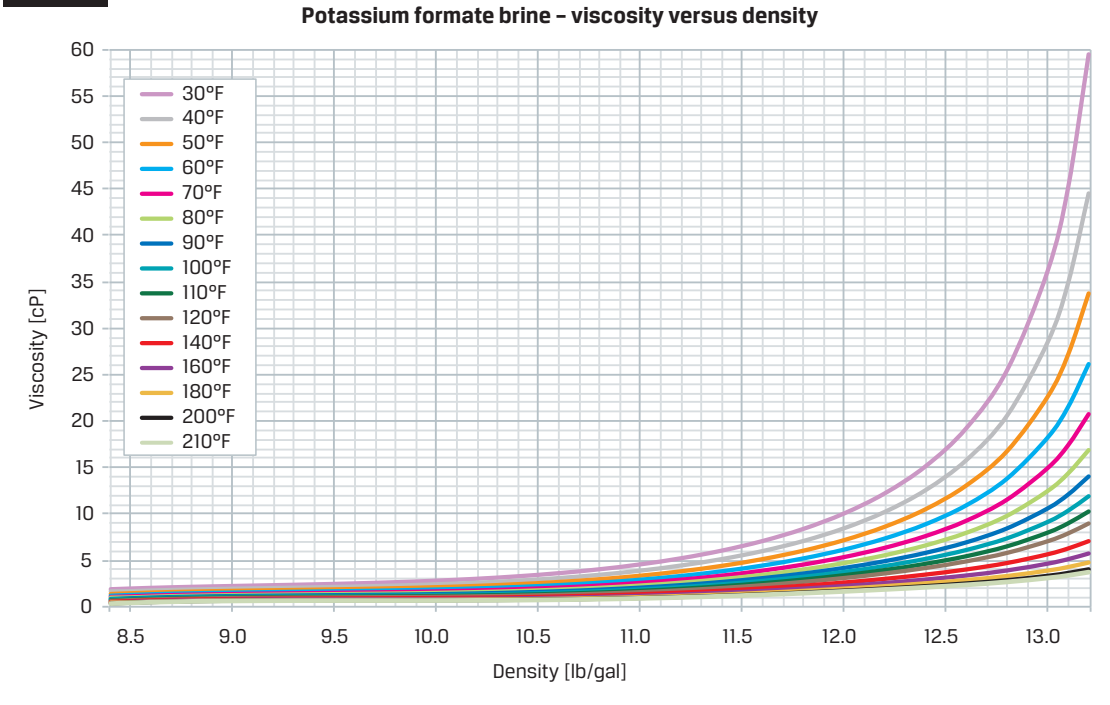
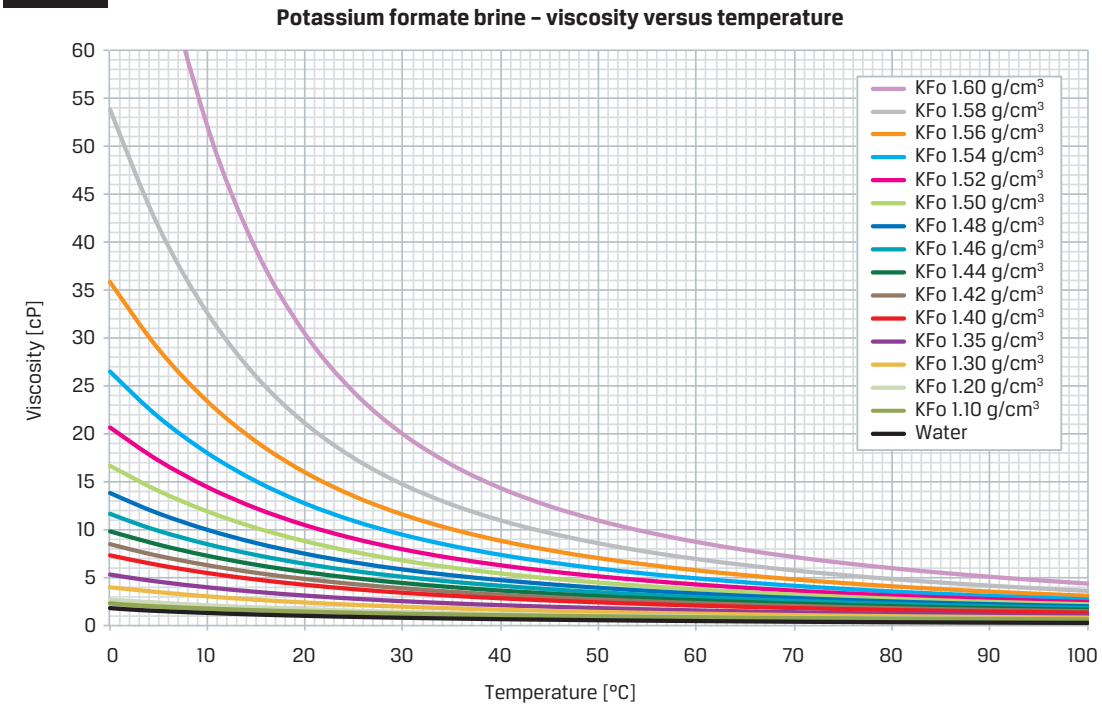


Figure 4 Viscosity of field-grade potassium formate as a function of density under various temperature conditions.

METRIC



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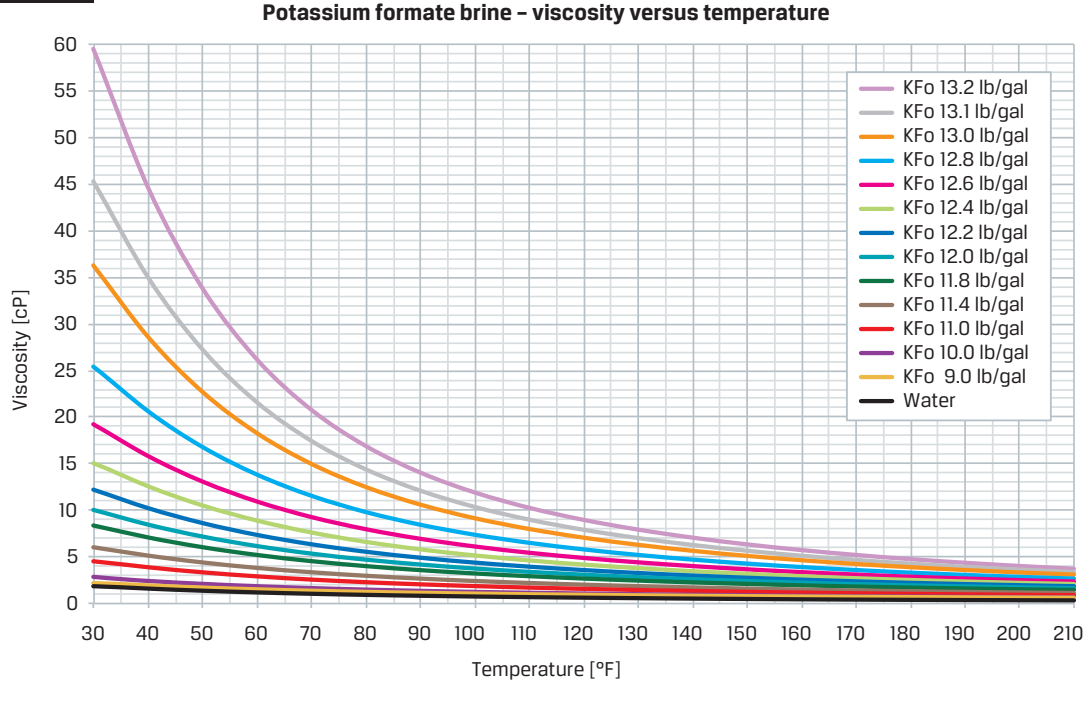


Figure 5 Viscosity of field-grade potassium formate brine with various densities as a function of temperature.

Table 5 Viscosity of field-grade cesium formate brine as a function of density and temperature in metric units.

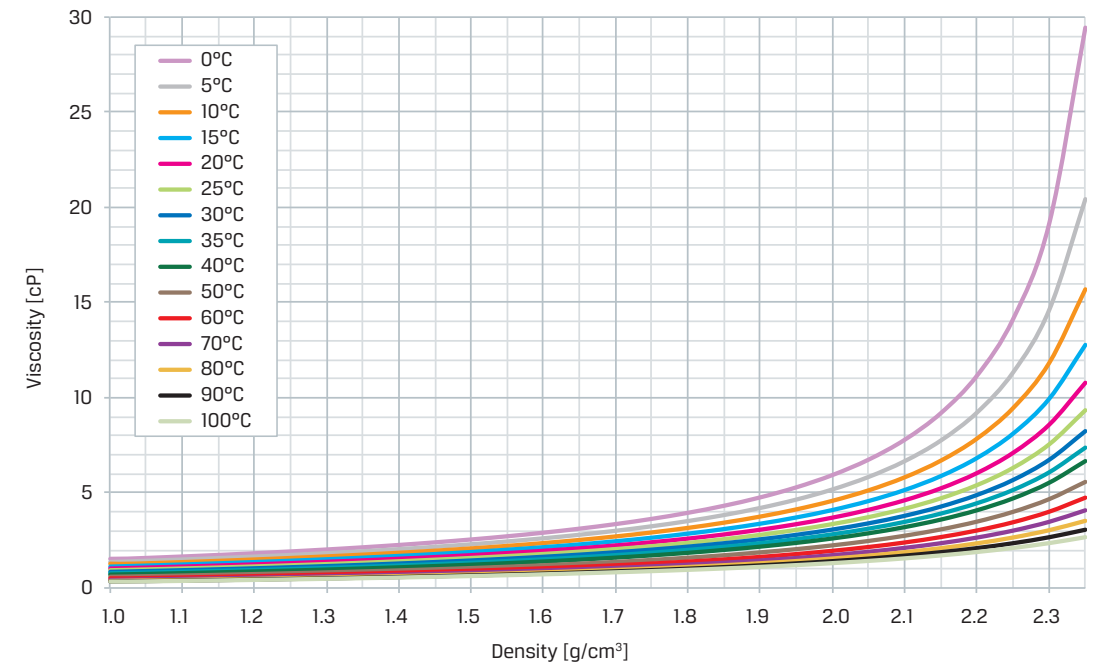
METRIC

Viscosity [cP]	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C	45°C	50°C	55°C	60°C	65°C	70°C	75°C	80°C	90°C	100°C
1.10 g/cm³	1.7	1.5	1.4	1.2	1.1	1.0	0.93	0.85	0.78	0.71	0.65	0.60	0.55	0.51	0.48	0.45	0.42	0.39	0.37
1.20 g/cm³	1.8	1.6	1.5	1.4	1.2	1.1	1.0	0.95	0.87	0.80	0.73	0.67	0.62	0.58	0.54	0.51	0.48	0.44	0.42
1.30 g/cm³	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.89	0.82	0.76	0.70	0.65	0.61	0.58	0.55	0.50	0.48
1.40 g/cm³	2.3	2.0	1.9	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.92	0.86	0.80	0.74	0.70	0.66	0.62	0.58	0.55
1.50 g/cm³	2.5	2.3	2.1	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	1.0	0.90	0.85	0.79	0.75	0.71	0.66	0.63
1.55 g/cm³	2.7	2.4	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	1.0	0.90	0.85	0.80	0.76	0.71	0.67
1.60 g/cm³	2.9	2.6	2.4	2.1	2.0	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.0	1.0	0.91	0.86	0.82	0.76	0.72
1.65 g/cm³	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.0	1.0	0.93	0.88	0.81	0.77
1.70 g/cm³	3.4	3.0	2.7	2.5	2.2	2.0	1.9	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.95	0.87	0.82
1.75 g/cm³	3.6	3.2	2.9	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.89
1.80 g/cm³	3.9	3.5	3.2	2.9	2.6	2.4	2.2	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0
1.85 g/cm³	4.3	3.8	3.4	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0
1.90 g/cm³	4.8	4.2	3.8	3.4	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.1
1.95 g/cm³	5.3	4.6	4.1	3.7	3.4	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2
2.00 g/cm³	5.9	5.2	4.6	4.1	3.7	3.4	3.1	2.8	2.6	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3
2.05 g/cm³	6.7	5.8	5.1	4.6	4.1	3.7	3.4	3.1	2.9	2.7	2.5	2.3	2.2	2.0	1.9	1.8	1.7	1.5	1.4
2.10 g/cm³	7.8	6.7	5.8	5.1	4.6	4.2	3.8	3.5	3.2	3.0	2.7	2.6	2.4	2.2	2.1	2.0	1.9	1.7	1.6
2.15 g/cm³	9.2	7.7	6.7	5.9	5.2	4.7	4.3	3.9	3.6	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	1.9	1.7
2.20 g/cm³	11	9.2	7.8	6.8	6.0	5.4	4.9	4.5	4.1	3.8	3.5	3.2	3.0	2.8	2.6	2.5	2.3	2.1	1.9
2.25 g/cm³	14	11	9.5	8.1	7.1	6.3	5.7	5.2	4.7	4.3	4.0	3.7	3.5	3.2	3.0	2.8	2.7	2.4	2.1
2.30 g/cm³	19	15	12	9.9	8.6	7.6	6.7	6.1	5.5	5.1	4.7	4.3	4.0	3.7	3.5	3.2	3.0	2.7	2.4
2.35 g/cm³	29	20	16	13	11	9.3	8.2	7.4	6.7	6.1	5.6	5.1	4.7	4.4	4.1	3.8	3.5	3.1	2.7

Table 6 Viscosity of field-grade cesium formate brine as a function of density and temperature in field units.

FIELD																			
Viscosity [cP]	**30°F**	**40°F**	**50°F**	**60°F**	**70°F**	**80°F**	**90°F**	**100°F**	**110°F**	**120°F**	**130°F**	**140°F**	**150°F**	**160°F**	**170°F**	**180°F**	**190°F**	**200°F**	**210°F**
9.0 lb/gal	1.7	1.5	1.3	1.2	1.1	1.0	0.88	0.79	0.72	0.65	0.59	0.54	0.49	0.46	0.42	0.40	0.38	0.37	0.36
10.0 lb/gal	1.9	1.7	1.5	1.3	1.2	1.1	1.0	0.90	0.82	0.74	0.68	0.62	0.57	0.53	0.50	0.47	0.45	0.43	0.42
10.5 lb/gal	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.0	0.87	0.80	0.73	0.67	0.62	0.57	0.54	0.51	0.48	0.47	0.46
11.0 lb/gal	2.1	1.9	1.7	1.5	1.4	1.2	1.1	1.0	0.93	0.85	0.78	0.72	0.66	0.62	0.58	0.55	0.52	0.51	0.50
11.5 lb/gal	2.3	2.0	1.8	1.6	1.5	1.3	1.2	1.1	1.0	0.92	0.84	0.77	0.72	0.67	0.63	0.59	0.57	0.55	0.54
12.0 lb/gal	2.4	2.2	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.90	0.83	0.77	0.72	0.68	0.64	0.61	0.59	0.58
12.5 lb/gal	2.6	2.3	2.1	1.9	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.90	0.84	0.78	0.74	0.70	0.67	0.64	0.63
13.0 lb/gal	2.8	2.5	2.2	2.0	1.8	1.6	1.5	1.4	1.2	1.1	1.1	1.0	0.91	0.85	0.80	0.76	0.72	0.70	0.68
13.5 lb/gal	3.1	2.7	2.4	2.2	2.0	1.8	1.6	1.5	1.4	1.2	1.1	1.1	1.0	0.92	0.87	0.82	0.79	0.76	0.74
14.0 lb/gal	3.3	2.9	2.6	2.4	2.1	1.9	1.8	1.6	1.5	1.3	1.2	1.2	1.1	1.0	0.95	0.90	0.86	0.83	0.80
14.5 lb/gal	3.7	3.2	2.9	2.6	2.3	2.1	1.9	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	1.0	0.94	0.90	0.87
15.0 lb/gal	4.0	3.5	3.1	2.8	2.5	2.3	2.1	1.9	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	1.0	1.0
15.5 lb/gal	4.5	3.9	3.5	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0
16.0 lb/gal	5.1	4.4	3.9	3.4	3.1	2.8	2.5	2.3	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
16.5 lb/gal	5.8	5.0	4.4	3.9	3.5	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.5	1.4	1.3	1.3
17.0 lb/gal	6.7	5.7	5.0	4.4	3.9	3.5	3.2	2.9	2.7	2.4	2.3	2.1	2.0	1.8	1.7	1.6	1.5	1.5	1.4
17.5 lb/gal	8.0	6.7	5.8	5.0	4.5	4.0	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.1	1.9	1.8	1.7	1.6	1.6
18.0 lb/gal	9.8	8.1	6.8	5.9	5.2	4.6	4.2	3.8	3.5	3.2	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.8
18.36 lb/gal	12	9.4	7.9	6.7	5.9	5.2	4.7	4.2	3.9	3.5	3.3	3.0	2.8	2.6	2.4	2.3	2.2	2.0	1.9
18.5 lb/gal	13	10	8.3	7.1	6.2	5.5	4.9	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5	2.4	2.2	2.1	2.0
19.0 lb/gal	18	13	11	8.9	7.6	6.7	5.9	5.3	4.8	4.4	4.0	3.7	3.5	3.2	3.0	2.8	2.6	2.4	2.3
19.5 lb/gal	28	19	14	12	9.8	8.4	7.4	6.6	5.9	5.4	4.9	4.5	4.2	3.8	3.5	3.3	3.0	2.8	2.6

METRIC



FIELD

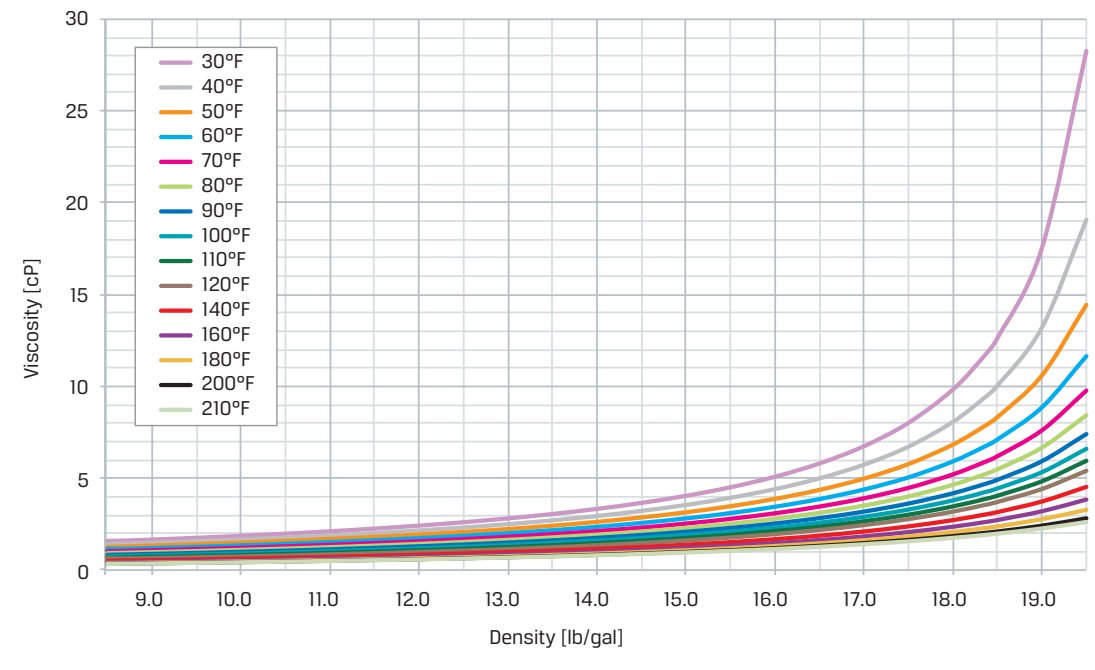
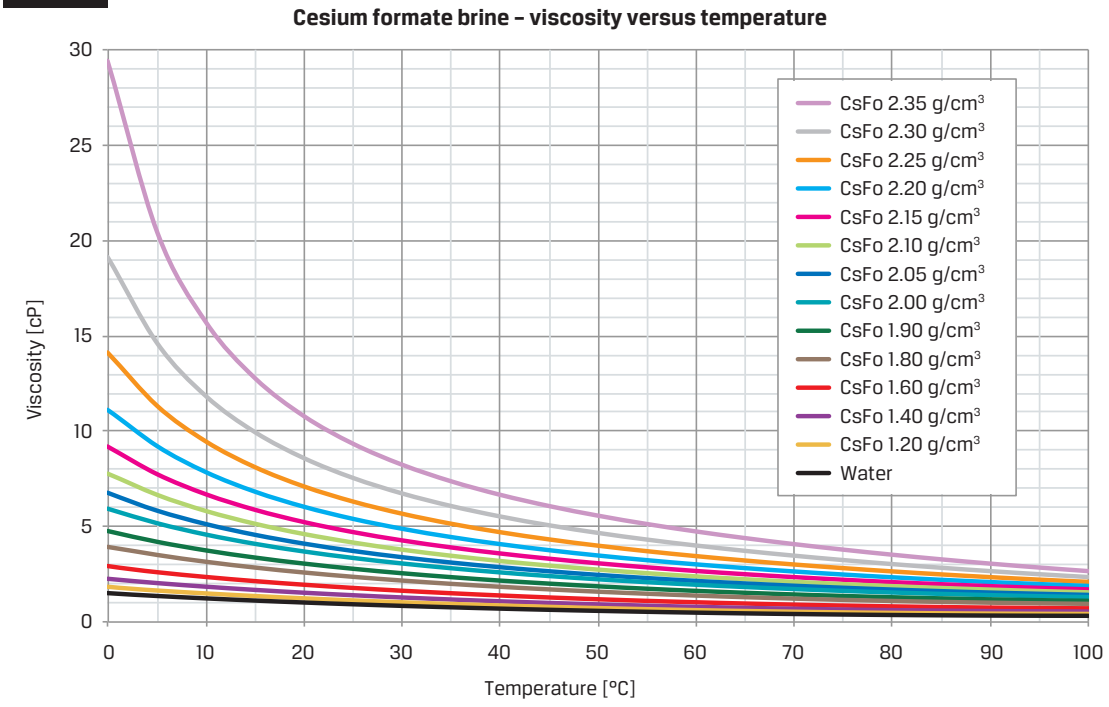


Figure 6 Viscosity of field-grade cesium formate as a function of density under various temperature conditions.

METRIC



FIELD

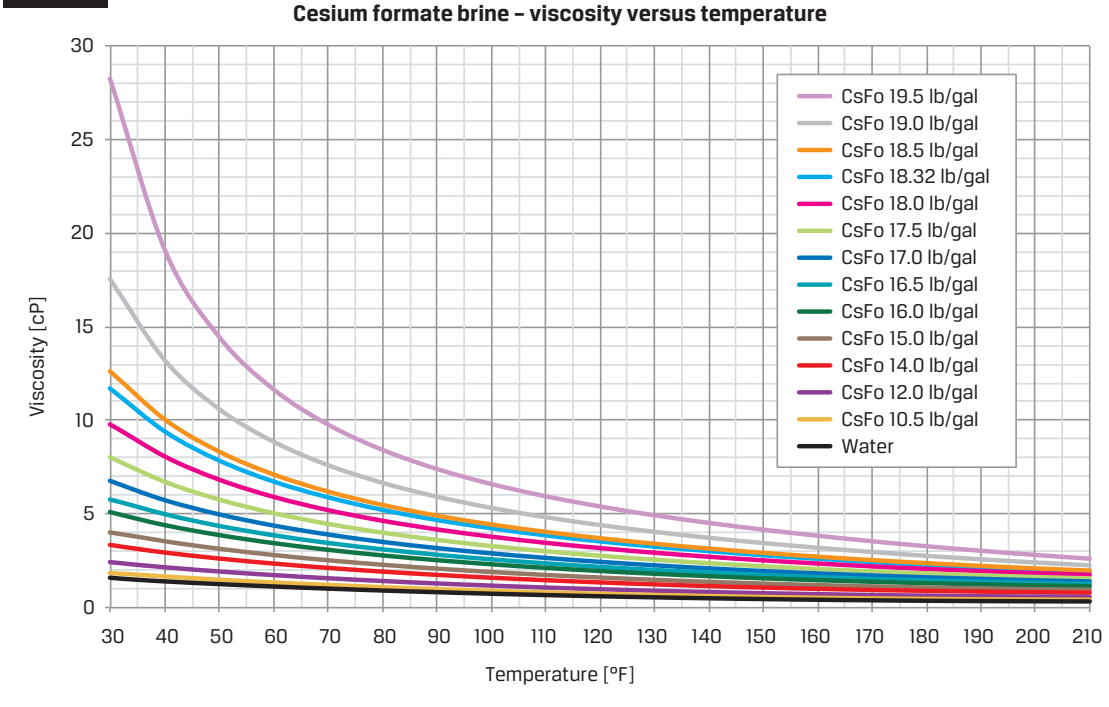


Figure 7 Viscosity of field-grade cesium formate brine with various densities as a function of temperature.

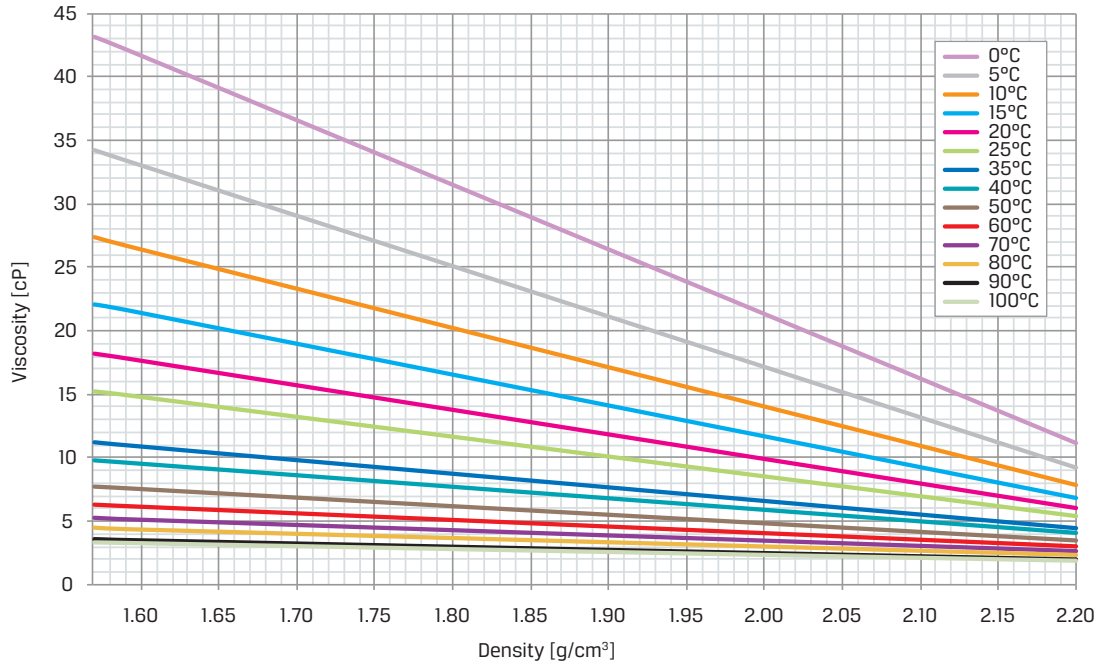
Table 7 Viscosity of standard blend 2.20 g/cm³ field-grade cesium formate and 1.57 g/cm³ field-grade potassium formate as a function of brine density and temperature in metric units. This table is only included as guidance. Blended cesium / potassium formate brines from Cabot are not always strict blends of these two stock brines.

METRIC																			
Viscosity [cP]	**0°C**	**5°C**	**10°C**	**15°C**	**20°C**	**25°C**	**30°C**	**35°C**	**40°C**	**45°C**	**50°C**	**55°C**	**60°C**	**65°C**	**70°C**	**75°C**	**80°C**	**90°C**	**100°C**
1.57 g/cm³	43	34	27	22	18	15	13	11	9.8	8.7	7.7	7.0	6.3	5.7	5.2	4.8	4.4	3.8	3.3
1.60 g/cm³	42	33	26	21	18	15	13	11	9.5	8.4	7.5	6.8	6.1	5.6	5.1	4.7	4.3	3.7	3.3
1.65 g/cm³	39	31	25	20	17	14	12	10	9.1	8.0	7.2	6.5	5.9	5.4	4.9	4.5	4.2	3.6	3.2
1.70 g/cm³	37	29	23	19	16	13	11	9.8	8.6	7.7	6.9	6.2	5.6	5.1	4.7	4.3	4.0	3.5	3.0
1.75 g/cm³	34	27	22	18	15	12	11	9.3	8.2	7.3	6.5	5.9	5.4	4.9	4.5	4.2	3.8	3.3	2.9
1.80 g/cm³	31	25	20	17	14	12	10	8.7	7.7	6.9	6.2	5.6	5.1	4.7	4.3	4.0	3.7	3.2	2.8
1.85 g/cm³	29	23	19	15	13	11	9.4	8.2	7.3	6.5	5.8	5.3	4.8	4.4	4.1	3.8	3.5	3.1	2.7
1.90 g/cm³	26	21	17	14	12	10	8.7	7.7	6.8	6.1	5.5	5.0	4.6	4.2	3.9	3.6	3.3	2.9	2.6
1.95 g/cm³	24	19	16	13	11	9.3	8.1	7.1	6.4	5.7	5.2	4.7	4.3	4.0	3.7	3.4	3.2	2.8	2.5
2.00 g/cm³	21	17	14	12	9.9	8.5	7.5	6.6	5.9	5.3	4.8	4.4	4.1	3.7	3.5	3.2	3.0	2.6	2.4
2.05 g/cm³	19	15	12	10	8.9	7.7	6.8	6.1	5.4	4.9	4.5	4.1	3.8	3.5	3.3	3.0	2.8	2.5	2.2
2.10 g/cm³	16	13	11	9.3	8.0	7.0	6.2	5.5	5.0	4.5	4.2	3.8	3.5	3.3	3.1	2.9	2.7	2.4	2.1
2.15 g/cm³	14	11	9.4	8.0	7.0	6.2	5.5	5.0	4.5	4.2	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.2	2.0
2.20 g/cm³	11	9.2	7.8	6.8	6.0	5.4	4.9	4.5	4.1	3.8	3.5	3.2	3.0	2.8	2.6	2.5	2.3	2.1	1.9

Table 8 Viscosity of standard blend 18.36 lb/gal field-grade cesium formate and 13.10 lb/gal field-grade potassium formate as a function of brine density and temperature in field units. This table is only included as guidance. Blended cesium / potassium formate brines from Cabot are not always strict blends of these two stock brines.

FIELD																			
Viscosity [cP]	**30°F**	**40°F**	**50°F**	**60°F**	**70°F**	**80°F**	**90°F**	**100°F**	**110°F**	**120°F**	**130°F**	**140°F**	**150°F**	**160°F**	**170°F**	**180°F**	**190°F**	**200°F**	**210°F**
13.1 lb/gal	43	34	27	22	18	15	13	11	9.8	8.7	7.7	7.0	6.3	5.7	5.2	4.8	4.4	4.1	3.8
13.5 lb/gal	41	32	26	21	17	15	12	11	9.3	8.3	7.4	6.7	6.0	5.5	5.0	4.6	4.3	4.0	3.7
14.0 lb/gal	38	30	24	20	16	14	12	10	8.8	7.8	7.0	6.3	5.7	5.2	4.8	4.4	4.1	3.8	3.5
14.5 lb/gal	35	28	22	18	15	13	11	9.4	8.2	7.3	6.5	5.9	5.4	4.9	4.5	4.1	3.8	3.6	3.3
15.0 lb/gal	32	25	20	17	14	12	10	8.7	7.7	6.8	6.1	5.5	5.0	4.6	4.2	3.9	3.6	3.4	3.1
15.5 lb/gal	29	23	18	15	13	11	9.2	8.0	7.1	6.3	5.7	5.2	4.7	4.3	4.0	3.7	3.4	3.2	3.0
16.0 lb/gal	26	21	17	14	11	9.7	8.4	7.4	6.5	5.8	5.3	4.8	4.4	4.0	3.7	3.4	3.2	3.0	2.8
16.5 lb/gal	23	18	15	12	10	8.8	7.6	6.7	6.0	5.4	4.8	4.4	4.0	3.7	3.4	3.2	3.0	2.8	2.6
17.0 lb/gal	20	16	13	11	9.1	7.8	6.8	6.0	5.4	4.9	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.6	2.4
17.5 lb/gal	17	13	11	9.2	7.9	6.9	6.0	5.4	4.8	4.4	4.0	3.7	3.4	3.1	2.9	2.7	2.5	2.4	2.2
18.0 lb/gal	14	11	9.2	7.8	6.7	5.9	5.2	4.7	4.3	3.9	3.6	3.3	3.0	2.8	2.6	2.5	2.3	2.2	2.0
18.36 lb/gal	12	9.4	7.9	6.7	5.9	5.2	4.7	4.2	3.9	3.5	3.3	3.0	2.8	2.6	2.4	2.3	2.2	2.0	1.9

METRIC



FIELD

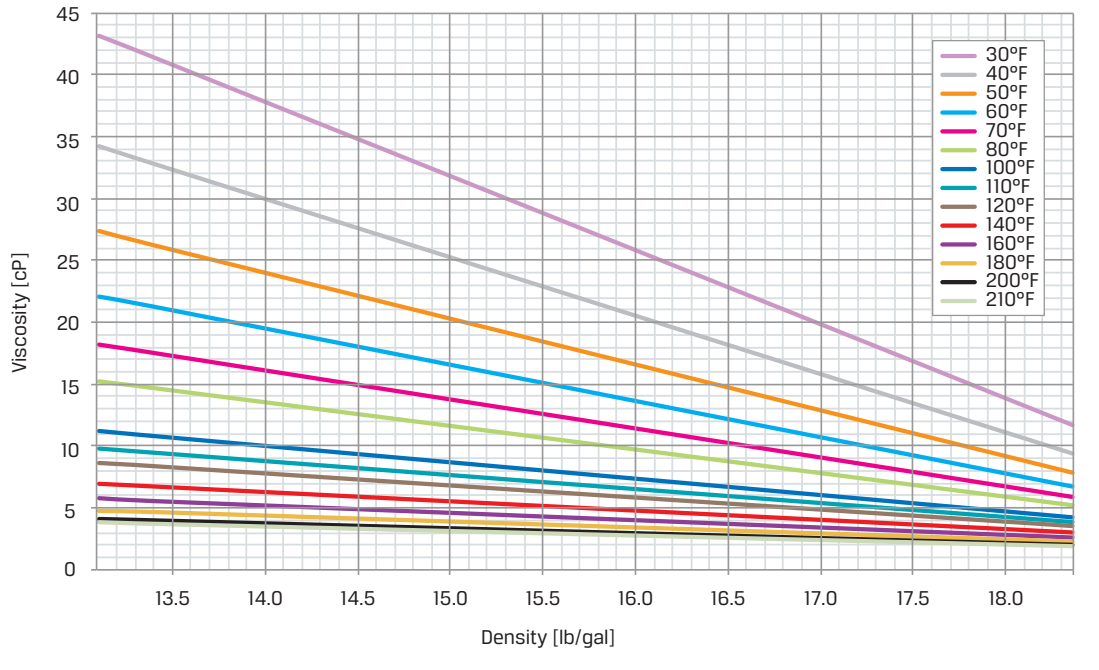


Figure 8 Viscosity of standard blend 2.20 g/cm³ / 18.36 lb/gal field-grade cesium formate and 1.57 g/cm³ / 13.10 lb/gal field-grade potassium formate as a function of brine density under various temperature conditions. These figures are only included as guidance. Blended cesium / potassium formate brines from Cabot are not always strict blends of these two stock brines.