COMPATIBILITIES AND INTERACTIONS

Section B7
Compatibility with Elastomers

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Specialty Fluids

B7.1 Introduction

Every type of drilling and completion fluid used in a well must be compatible with the elastomer and seals used in downhole tool and surface rig equipment. Incompatibilities between the fluid and elastomers can result in trips to repair equipment, leaks, and catastrophic failure of safety equipment.

B7.2 General recommendations

Results from a variety of tests show that common elastomers generally perform as specified by the manufacturer when exposed to formate brines. Formate brines are buffered to maintain an alkaline pH during field use. Some elastomers are not compatible with alkaline fluids. Examples are NBR (Nitrile) and FKM (Viton®). Both of these elastomers are not compatible with alkaline fluids, especially at high temperatures. The low tolerance of FKM (Viton®) to high pH fluids is due to the presence of vinylidene fluoride. It is important to notice, however, that although the brine contact stiffens both NBR and KFM as measured at ambient temperature, the elastomer will be less stiff at service temperature.

In order to improve resistance, Du Pont developed the base resistant FKM, Viton® ETP, in which the vinylidene fluoride is replaced by an olefin. Viton® ETP shows good performance in formate brines. However, one would need to be aware of some possible incompatibilities at higher temperatures if this elastomer is filled with silica fume.

Whilst NBR is considered unacceptable for service in formate brines at temperatures above 120°C / 248°F for extended periods, the HNBR (hydrogenated Nitrile) possesses higher levels of chemical and thermal resistance than NBR and performs satisfactorily at much higher temperatures.

Table 1 gives general guidelines for elastomer performance in formate brines. When using this table, one would need to keep in mind that these guidelines are based on a limited number of tests conducted under a limited set of test conditions. Detailed descriptions of the tests that the guidelines are based on are presented in Section B7.3.

It is difficult to judge service performance based on laboratory testing. Laboratory tests are often performed on O-rings or elastomer sheets that are fully immersed in the fluid. Under service conditions, the fluid can often contact only a small portion of the seal.

FEPM (Aflas®), FFKM (Kalrez®, Chemraz®), base resistant fluoroelastomers, FFKM, HNBR, and PEEK®

Table 1 Quick guidelines for elastomer performance in formate brines. These guidelines are based on tests where formates have shown compatibility with the elastomer. Detailed descriptions of these tests and other tests are presented elsewhere.

Elastomer type*	Test. conditions			Recom-mended	Comments
	Temp. °C	Temp. °F	Time		
FEPM (Aflas®) (TFE/P)	204	400	7 days	✔	
	175	347	8 weeks		
FFKM (Kalrez® Chemraz®)	191	375	7 days	✔	
EPDM	120	248	8 weeks	✔	Brittle at higher temperatures
NBR	120	248	8 weeks	!	Performance depending on pH and temperature
HNBR	191	375	7 days	✔	
	175	347	8 weeks	✔	
FKM (Viton®)	120	248	8 weeks	!	Performance depending on pH, temperature, and exposure time.
Base resistant FKM (Viton® ETP)**	163	325	3 weeks	✔	Variable performance at the highest test temperature. Silica fume filling might cause incompatibility at higher temperatures.
	170	338	8 days		
	177	350	4 weeks		
	200	392	7 days		
PEEK	180	356	7 days	✔	
Grafoil®	170	338	8 days	✔	

The following acceptance guidelines have been used:
<15% volume (or hardness) change
<35% tensile strength (or elongation) change.

* Elastomer type – relates to this entire group of elastomers.
** Also denoted as FEPM by ASTM D140, although its structure and physical and chemical property profiles are significantly different.

appear to be good sealing materials in high temperature formate brines. If there is any doubt about the performance of any specific elastomer under any particular set of conditions, testing under the specific field conditions is always recommended.

During the eight years that cesium formate has been used in HPHT well construction operations, there has never been an elastomer failure caused by exposure to cesium formate brines or blends.

B7.3 Elastomer tests – detailed results

Several companies have completed extensive studies on common oilfield elastomers exposed to formate brines. In addition, some testing has been conducted as required by operators for specific elastomers and tools.

It should be noted that tensile strength and elongations in tension are failure properties that typically exhibit a lot of data scatter (+/- 20%). Therefore, any of these after-test properties that vary up to +/- 20% may be simply noise in the test data.

B7.3.1 Testing at Westport

Westport Technology Center International tested the compatibility of a range of commonly used elastomers with cesium formate brine [1]. The tests were run for seven days in a Hastalloy autoclave at three sets of temperature / pressure conditions:

1. 191°C / 375°F, atmospheric pressure
2. 177°C / 350°F and 5,000 psi
3. 200°C / 392°F and 15,000 psi

The cesium formate brine was buffered to a pH of 10.

Most of the elastomers tested performed satisfactorily with the exception of the Vitons (GT-926-08 and Baker-9009), which were tested above their recommended pH limits.
The results of the tests are shown in Table 2.

B7.3.2 Testing reported by Shell

Shell Research has reported elastomer compatibility testing in potassium and cesium formate brines [2]. The tests were conducted for Shell Research by MERL, U.K. and Halliburton Energy Services, Dallas, TX. Some of these tests were done at temperatures higher than recommended by the elastomer manufacturer. The results of the tests conducted in the correct temperature range are shown in Table 3. Based on these results, it was concluded that formate brines are incompatible with Vitons because of the pH limitations of this elastomer.

Table 2 Results from tests of elastomers after seven days' exposure to buffered cesium formate. The tests were performed by Westport at 191°C / 375°F [1].

Type	Sample	Temperature		Days	Change in sample after test [%]					Appear-ance
		°C	°F		Vol.	Wt.	Hard.	Ten. Str.	Elon.	
Aflas®	GT-799-08	191	375	7	-7.4	-0.4	0.0	21.3	-16.6	OK
	GT-790-10	191	375	7	-2.3	0.9	-4.2	28.2	-21.5	OK
	PARCO-2902	191	375	7	1.2	0.3	-5.1	-7.0	1.9	OK
	Baker-7116	191	375	7	0.2	0.1	1.2	-2.2	-3.0	OK
Viton®	GT-926-08	191	375	7	12.4	1.3	--	--	--	Brittle
	Baker-9009	191	375	7	5.9	0.6	--	--	--	Brittle
Chemraz®	GT-5220062	191	375	7	-5.7	0.2	0.0	7.2	17.4	OK
	GT-5100130	191	375	7	-1.7	1.7	0.0	2.7	12.4	OK
Kalrez®	PARCO-3018	191	375	7	0.4	0.3	0.0	-18.7	-24.0	OK
	PARCO-1050*	191	375	7	--	0.3	--	--	--	OK
HNBR	Baker-2013	191	375	7	3.1	3.8	11.1	-7.7	-32.3	OK
Viton®	Baker-9009	191	375	7	5.9	0.6	--	--	--	Brittle
NBR	Baker-4177	191	375	7	-5.1	-2.3	7.1	-21.8	-45.9	OK
ETP	Baker #1	149	300	7	1.1	Not run	-2.0	-34.0	-23.0	OK
	Baker #1	200	392	7	1.7	Not run	-1.0	-63.0	-45.0	--
	Baker #2	149	300	7	0.8	Not run	-2.0	-10.0	-17.0	OK
	Baker #2	200	392	7	1.5	Not run	-4.0	-19.0	-27.0	--
	Baker #3	149	300	7	3.9	Not run	0.0	-17.0	2.0	OK
	Baker #3	200	392	7	6.6	Not run	-10.0	59.0	23.0	--
	Baker #4	149	300	7	5.0	Not run	-2.0	-2.0	-40.0	OK
	Baker #4	200	392	7	8.6	Not run	-2.0	-34.0	-41.0	--

* O-ring sample instead of coupon.
GT = Greene, Tweed & Co.

Table 3 Elastomer testing as reported by Shell [2]. The elastomers were exposed to concentrated unbuffered potassium formate brine for seven days and eight weeks and to a concentrated unbuffered cesium formate brine for seven days. Cesium formate was tested at pH=12.6 (undiluted) (> realistic field conditions) and potassium formate was tested at pH 10.5 (undiluted).

Type	Specification	Brine type	Test temp.		Change in sample after test [%]					
					Thickness		Weight		Hardness*	
			°C	°F	7d	8w	7d	8w	7d	8w
Aflas® (FCM / FEPM)	Aflas® 790	KFo	120	248	-1.2	+0.2	0	+0.7	+1.1	0
			175	347	+0.4	+0.3	+1.2	+2.5	-1.1	-2.1
	Aflas® 7182B	KFo	120	248	-1.1	+0.1	0	-0.6	0	+1.1
			175	347	-0.5	-0.7	+6.3	-0.1	+1.1	+1.1
	?	CsFo	180	356	0.4		-0.5		-0.2	
CR	Neoprene 7065	KFo	120	248	+0.1	+1.2	0	+0.8	0	+1.1
EPDM	EPDM 7204	KFo	120	248	-2.1	+0.1	0	-0.1	-10.6	-1.2
			175	347	-0.4	-0.5	+0.3	+0.1	+5.7	+6.9[b)]
	EPDM 5778-90	KFo	120	248	-1.8	0	0	+1.0	+10.7	0
NBR[1)]	Nitrile 4058-90	KFo	120	248	-2.1	+0.3	0	+2.3	+4.5	+10.5
HNBR[1)]	HNBR 2269	KFo	120	248	-2.2	+0.3	0	+1.4	-1.1	+1.1
	Carboxyl. HNBR 2311-90	KFo	120	248	-1.4	+0.3	0	+3.7	+11.5	+4.4
			175	347	-1.3	-7.2	+15.5	+11.6	0	+6.5
	Carboxyl. NBR 2067-90	KFo	120	248	-2.2	+0.4	0	+2.2	0	+3.5
FKM ('Viton®')[2)]	Fluorel 71481	KFo	120	248	+2.7	-0.1	0	+0.7	0	+1.1
			175	347	+0.2	-6.2	-26.6	-12.0	-1.6	+2.6[w)]
	Viton® TC 1220-11	KFo	120	248	+2.3	+0.8	0	0	-2.1	+1.1
			175	347	+1.0	-2.9	-0.3	-7.0	-1.6	+2.1[w)]
	Viton® TC 1220-12	KFo	120	248	-0.2	+0.8	0	+2.7	-3.1	+3.3
			175	347	+4.0	+29.0	+15.9	+28.7	-1.1[b)]	-13.7
	Viton® 9062-95	KFo	120	248	+0.2	+0.3	0	+2.5	-2.1	+2.2[b)]
			175	347	+0.6	+1.7	-1.4	-20.9	0[w)]	+1.1[w)]
	?	CsFo	180	356	x)		x)		x)	
PEEK®	PEEK® / glass filled	CsFo	180	356	1.0[c)]		-0.3		6.2[3)]	
Kalrez® (FFKM)	?	CsFo	180	356	0.3		0.4		0.3	

* The hardness measurement was difficult to perform due to the shape of the elastomer, and the results should be taken as indications rather than absolute values.
b) brittle, w) weak, c) change in cross sectional area, d) tenacious crystalline deposits, x) catastrophic deterioration.

1) HNBR and NBR cannot be used in $CaBr_2$ and $ZnBr_2$ as they harden due to crosslinking. Based on these results, such crosslinking seems not to occur in the monovalent formate brines.
2) FKMs (Fluorocarbons) are very often attacked by alkali solutions (pH>10), which can explain the bad performance in the concentrated formate brines (pH ~ 10.5).
3) Build-up of tenacious crystalline deposits.

The other elastomers that were tested performed satisfactorily.

B7.3.3 Baker Oil Tools testing

Baker Oil Tools included cesium formate brine in a test program where nine different elastomers were tested for compatibility with five different fluids [3]. The elastomers included in these tests were nitrile (NBR), a hydrogenated nitrile or HNBR, an incorporated cure FKM fluoroelastomer (Viton®E60C), an FEPM (Aflas®), a FFKM (Kalrez®), and four different compounds of Viton® Extreme ETP. The elastomers were exposed for seven days at two temperatures 150°C / 302°F and 200°C / 392°F, apart from NBR that was only tested at 150°C / 302°F. The high temperature tests were performed at 103 MPa / 15,000 psi and the low temperature tests at 34 MPa / 5,000 psi. Swelling test samples were removed from the test cell after four and 24 hours to find out what short-term effects the fluid would have on the elastomers. The results of the tests are listed in Table 4. As can be seen, the FFKM (Kalrez®) had significant changes in mechanical strength. This is out of line with other tests on this elastomer. It is the same for NBR at 150°C / 302°F. Again, FKM (Viton®) was tested outside of the suppliers recommended pH range, and therefore suffered substantial changes in properties at 150° / 302°F.

Table 4 Results of elastomer testing after seven days' exposure to a buffered cesium formate brine. The tests were performed by Baker Oil Tools [3]. The 150°C / 302°F tests were performed at 34 MPa / 5,000 psi and the 200°C / 392°F tests at 15,000 psi.

	Temperature		Tensile	Elong.	25% modu-lus	50% modu-lus	Hard-ness change	Volume swell	Hardness swell after 4 hrs		Hardness swell after 24 hrs	
	°C	°F	[%]	[%]	[%]	[%]	[%]	[%]		[%]		[%]
NBR	150	302	-7	-57	132	121	3	-5	0	-0.9	0	-1.4
HNBR	150	302	-5	-8	-10	-11	1	1.0	2	0.0	2	0.1
	200	392	Broke in grips						0	0.0	0	-7
FKM (Viton®)	150	302	-51	-53	-22	-10	4	6.2	1	-0.3	1	0.2
	200	392	Broke in grips						0	4.4	1	3.9
FEPM (Aflas®)	150	302	9	-1	-42	-13	-1	3.4	0	-0.2	0	0.4
	200	392	-10	-22	112	53	4	3.8	-3	3.8	-3	2.7
FFKM (Kalrez®)	150	302	-66	-57	-2	8	-0	2.0	1	0.0	1	0.0
	200	392	-64	-15	-95	-81	-6	6.9	0	1.0	1	2.8
ETP 1	150	302	-34	-23	-46	-9	-2	1.1	1	0.7	1	0.5
	200	392	-63	-45	-43	-20	-1	1.7	-2	-1	-1	0.4
ETP 2	150	302	-10	-17	-15	5	-2	0.8	1	0.2	1	0.3
	200	392	-19	-27	-48	17	-4	1.5	1	1	0	-4.8
ETP 3	150	302	-17	2	-24	-7	0	3.9	-3	-0.1	-3	1.1
	200	392	59	23	-28	5	-10	6.6	0	5.8	-6	7.3
ETP 4	150	302	-2	-40	6	38	-2	5.0	1	1.0	1	0.9
	200	392	-34	-41	-15	-9	-2	8.6	1	4.7	-1	3.0

B7.3.4 MERL testing of Viton® ETP and Grafoil®

Samples of Viton® Extreme 90 (Viton® ETP) elastomer and Grafoil® were exposed to a blended cesium / potassium formate brine for eight days at 170°C / 338°F [4]. The tests were carried out by MERL for Cabot Specialty Fluids.

Viton® Extreme 90

Twenty tensile samples were die cut from a molded sheet of Viton® Extreme 90. Two sets of five samples were weighed together in air and water in order to measure starting mass and volume of the bars. Mass and volume changes were measured on a regular basis throughout the exposure period. At the end of the exposure period one set of five samples were tested at room temperature and at 6°C / 43°F. For all samples very small differences in properties were measured between aged and unaged samples, suggesting negligible influence of formate brine on mechanical properties of these materials. The changes in mass (<0.15%) as a function of time are shown in Table 5 along with the volume changes, which are also well within the acceptable limits for sealing elastomers. Results of tensile measurements are listed in Table 6. All properties showed very little change as a result of the exposure. In summary, the Viton® Extreme is resistant to formate brine under the exposure conditions employed and there is no evidence to suggest that longer-term immersion would significantly alter this.

Grafoil®

Two cylindrical Grafoil® samples were cut in half horizontally to provide four equally sized samples. Samples were weighed in air and water to determine starting mass and volume of the cylinders. One half of each sample was used for the exposure testing. Mass and volume changes were measured on a regular basis during exposure. At the end of the exposure period all four samples were compression tested at room temperature at 1 mm / min. Modulus at 5% and 10%, maximum load, elongation at max. load, and compressive strength were measured. During exposure one of the samples uncoiled and the other did not. The test results for the samples that uncoiled and the ones that did not uncoil are listed in Table 5 and Table 7. Although large differences between mass uptake and volume swell were recorded between the uncoiled and the coiled samples, there was very little difference between the aged and the unaged specimens in the coiled and uncoiled state, suggesting that the formate brine does not significantly degrade the material.

B7.3.5 Halliburton testing

Halliburton Energy Services carried out a study on the effect of completion brines on elastomers [5]. This included compatibility testing of three elastomers: FKM (Viton®), TFE/P, and ETP in a 1.86 s.g. / 15.5 ppg buffered cesium / potassium formate brine blend with pH = 9. The elastomers, which are all rated for temperatures up to 204°C / 400°F, were tested at

163°C / 325°F and 193°C / 380°F. The elastomers were exposed to the formate brine for three weeks and tested after 24 hours, 48 hours, one week, two weeks, and three weeks. The testing included hardness, thickness, and ASTM D412 tensile properties (TB, EB, M50, M100). This study concluded that FKM (Viton®) is incompatible with alkaline formate brines due to its pH limitation. The ETP and TFE/P performance was found to be mixed and highly dependent on the test temperature. Changes in hardness were found to be less than 1.1% at all conditions. It is unknown whether the ETP elastomers were filled with silica fume (see section B7.3.6). The test results are shown in Table 8.

B7.3.6 Du Pont testing

Du Pont included a cesium / potassium formate brine in a recent study on the compatibility between high-performance fluoroelastomers and some HPHT oilfield fluids [6]. The elastomers that were tested are Viton® A-HV (A40-06), Viton® GF-S (A40-04), Viton® ETP-S (A40-01), and Viton® ETP-S with Si (A40-02). Testing was conducted by immersion of dumbbells in the fluid inside a sealed Parr vessel for four weeks at elevated temperatures (150°C / 302°F and 177°C / 350°F) and autogenous pressure with the vessel allowed to cool before opening. The test results are listed in Table 9. The results show as expected that the standard FKM fluoroelastomer Viton® A-HV was embrittled from exposure to the formate brine due to its lack of compatibility with alkaline fluids. The peroxide cured, high fluorine content FKM, Viton® GF-S, suffered a high loss of tensile and elongation with a modest loss of modulus. It also embrittled at the highest temperature. This is also as expected as the peroxide curing chemistry gives it better acid resistance and would therefore not be expected to improve its compatibility with alkaline fluids. Both base resistant FKM (Viton® EPT-S) samples performed well at the lower temperature and the black filled sample also performed well at the higher temperature. Viton® ETP is concluded to be fully compatible with formate brines, but one would need to be aware of some incompatibilities at higher temperature if this elastomer is filled with silica fume.

B7.3.7 Neyrfor Turbine HNBR

Two alternative HNBR elastomer samples (HN1662-1 and HN-1662-2) used in Neyrfor turbines were exposed to a buffered cesium formate brine for three and seven days at 152°C / 305°F. The tests were conducted at Westport Technology Center International [7]. The elastomers were tested for changes in weight, volume, hardness, and appearance. Both elastomer samples were concluded to be compatible with cesium formate under the test conditions (Table 10), and they did not exhibit any change in appearance.

B7.3.8 Petroline Well-Systems Aflas®

An Aflas® sample from Petroline Well-Systems was exposed to a buffered cesium formate brine for seven days at 204°C / 400°F and tested for compatibility. The tests were carried out at Westport Technology Center International [8]. Table 11 lists measured changes in volume, weight, and hardness. The elastomer did not exhibit any significant changes in the measured properties or its appearance, and was concluded to be compatible with the formate brine.

Table 5 Elastomer mass uptake and volume swell measurements after exposure to a buffered cesium / potassium formate brine at 170°C / 338°F. Testing was carried out by MERL [4].

	Mass change		Volume change	
	Room temperature	6°C / 42.8°F	Room temperature	6°C / 42.8°F
	[%]	[%]	[%]	[%]
Viton® Extreme 90				
4.75 hours	0.17	0.14	0.11	0.05
6.75 hours	0.31	0.23	0.11	0.87
9.75 hours	0.29	0.26	0.27	0.30
13.75 hours	0.12	0.20	-0.21	0.40
Grafoil® (sample that did not uncoil)				
4.75 hours	6.16		3.08	
6.75 hours	7.09		3.16	
9.75 hours	6.11		4.54	
13.75 hours	5.84		3.16	
Grafoil® (sample that uncoiled)				
4.75 hours	30.56		4.17	
6.75 hours	32.52		6.73	
9.75 hours	32.30		9.36	
13.75 hours	33.72		9.58	

B7.3.9 Polymyte, Molythane, and Shaffer Nitrile

Two elastomers (Polymyte and Molythane) and five Shaffer nitrile rubbers were tested for compatibility with cesium formate brine. These elastomers are elements of Shaffer-Varco's BOP. The elastomers were exposed to the buffered cesium formate brine (1.92 s.g. / 16 ppg) at 93°C / 200°F for 48 hours and seven days [9]. Changes in volume, weight, hardness, and appearance are listed in Table 12. All of the elastomers tested appear to be compatible with formate brines under the test conditions.

B7.3.10 Cameron nitrile, CAMLAST™ and DUROCAM™

Three elastomers from Cameron were tested for compatibility with cesium formate brine. The elastomers were tested after a seven-day exposure to a 1.7 s.g. / 14.2 ppg buffered (pH = 10) cesium formate brine at 100°C / 212°F and 121°C / 250°F.

The Cameron elastomeric materials evaluated were nitrile elastomer compounds used in the fabrication of ram packers / top seals, VBR packers, annular packers / donuts; and CAMLAST™ and DUROCAM™ elastomers used in high temperature / H_2S resistant ram packers / top seals and shearing blind ram side and blade packers.

Results of the compatibility testing of Cameron's nitrile, CAMLAST™, and DUROCAM™ elastomers indicated minimal detrimental effects on the elastomers during the seven days' exposure [10].

B7.3.11 MERL testing for North Sea HPHT well

A limited test program was undertaken by MERL to help increase confidence for selection of elastomers for a North Sea HPHT well [11]. Five elastomers were exposed to a 1.73 s.g. / 14.42 ppg buffered cesium / potassium formate brine at 185°C / 365°F for up to nine days. The elastomers that were tested were fluoroelastomer gun seals (V858-95), a pair of PEEK® (split) back-up rings and single short sections of Aflas® and NBR. The tests, which are listed in Table 13, confirm that Viton® is not suited for these specific HPHT well conditions. The NBR sample, which was tested outside of its recommended temperature limit of 120°C / 248°F, remained flexible for the first period of the test (still flexible after 37 hours), but stiffened with time. Both the PEEK® and the Aflas® sample performed very well. The same was the case for the Viton® ETP sample, although one of the samples had split, likely during cleaning.

B7.3.12 Westport testing of FEPM and FKM

An immersion test was performed for three elastomeric seals (CDI 904-90 FEPM, CDI 908 LS FKM, CDI 928 FKM) in a buffered cesium formate brine (added 5% *KCl*) at 200°C / 392°F for 48 hours [12]. The results are shown in Table 14. As can be seen none of the coupons exhibited significant swelling and weight gain. All of the three CDI 904-90 FEPM coupons performed very well, whereas CDI 908 LS FKM experienced severe blistering and cracking.

Table 6 Tensile data for unaged and aged Viton® Extreme 90 samples after eight days' exposure to a potassium / cesium formate brine at 170°C / 338°F. The testing was carried out at MERL [4].

No.	Thickness [mm]	Width [mm]	Area [mm²]	Gauge length [mm]	Mod. at 50% [MPa]	Elongation at break [%]	Tensile strength [MPa]
Unaged at room temperature							
2	2.16	3.93	8.4888	22.67	10.89	98.26	20.44
2	2.16	3.96	8.5536	21.57	10.35	105.94	20.12
3	2.17	3.96	8.5932	21.99	9.63	84.7	16.4
Unaged at 6°C / 43°F							
1	2.16	3.94	8.5104	19.67	16.61	101.58	27.28
2	2.07	3.95	8.1765	19.95	16.51	74.6	22.69
3	2.16	3.98	8.5968	21.24	16.47	83.71	24.15
Brine aged tested at room temperature							
1	2.14	3.93	8.4102	20.89	9.9	114.94	20.93
2	2.18	3.96	8.6328	22.08	8.82	121.76	20.22
3	2.16	3.97	8.5752	21.24	10.68	102.72	20.17
Brine aged – tested at 6°C							
1	2.16	3.97	8.5752	20.71	15.85	92.44	24.93
2	2.17	3.99	8.6583	20.82	15.99	89.75	24.95
3	2.17	3.93	8.5281	21.29	16.53	86.28	24.84

Table 7 Compressive data for unaged and aged Grafoil® samples after eight days' exposure to a buffered potassium / cesium formate brine at 170°C / 338°F. The testing was carried out by MERL [4].

No	OD	ID	Sample height	Mod. at 5%	Mod. at 10%	Max. load	Elongation at yield	Compressive strength
	[mm]	[mm]	[mm]	MPa	[MPa]	[%]	[%]	[MPa]
Uncoiled								
Unaged	17.15	6.5	6.15	1.04	3.01	1,018	20.61	5.16
Aged	17.15	6.5	6.54	1.26	3.06	859	20.91	4.35
Coiled								
Unaged	17.15	6.5	7.36	2.32	6.13	1,500	16.26	7.6
Aged	17.15	6.5	6.52	1.16	5.14	1,444	13.92	7.31

Table 8 Results of Halliburton Elastomer testing [5]. The elastomers were exposed to a buffered potassium / cesium formate brine for one and three weeks at two different temperatures. There was less than 1.1% change in hardness for all three temperature / time conditions.

Elastomer	Temperature		Change in sample after test [%]					
			Tensile strength		Elongation to break		Modulus at 50%	
	[°C]	[°F]	1 week	3 weeks	1 week	3 weeks	1 week	3 weeks
ETP	163	325	+7	+7	-11	-4	+18	+6
	193	380	-50	---	-67	---	+1	---
TFE/P	163	325	-2	~ 0	-9	-12	+4	+19
	193	380	-18	---	+16	---	-18	---

Table 9 Du Pont tests of fluoroelastomers exposed to a cesium / potassium formate brine [6]. The elastomers were exposed to the formate brine for 28 days at 150°C / 302°F and 177°C / 350°F.

Elastomer type		Temperature		Hardness	Change in physical properties			
					M50	Tb	Eb	Volume
		[°C]	[°F]	[pts]	[%]	[%]	[%]	[%]
ETP-S	A40-01	150	302	0	11	11	8	0
		177	350	0	11	20	24	-1
ETPS w/silica	A40-02	150	302	1	26	4	-7	0
		177	350	1	29	-30	-58	0
GF-S	A40-04	150	302	-7	-6	-53	-44	-10
		177	350	-10	-100	-92	-83	-21
AHV	A40-0	150	302	-8	-100	-78	-82	-10
		177	350	-20	-100	-85	-92	-14

Table 10 Testing of Neyrfor turbine HNBR at 152°C / 305°F after three and seven days' exposure to buffered cesium formate brine.

Sample	Test duration	Change in sample after test [%]			Appearance
		Weight	Volume	Hardness	
HN1662-1	3 days	-0.1	-0.4	No change	No change
	1 week	+0.6	-1.4	No change	No change
HN1662-2	3 days	0.0	-1.0	No change	No change
	1 week	+0.1	-1.0	No change	No change

Table 11 Testing of Aflas® samples from Petroline Well-Systems after exposure to cesium formate for seven days at 204°C / 400°F.

Sample	Change in sample after test [%]					
	Weight	Volume	Hardness	Tensile strength	Elongation	Appearance
Aflas® 1	+0.2	-3.4	0	-12.3	-8.8	No change
Aflas® 2	+1.0	-0.5	0	-4.9	-0.4	No change
Aflas® 3	+1.4	-2.2	0	+5.6	+3.2	No change

Table 12 Testing of two Shaeffer elastomers and five nitrile rubbers exposed to buffered cesium / potassium formate brine at 93°C / 200°F [9].

	Time [days]	Change in property [%]						Appearance
		Weight	Volume	Hardness	Tensile stress	Elongation	Modulus at 200%	
Polymyte 4651	2	+0.1	-0.3	0	+0.8	-7.8	-0.2	No change
	7	+0.1	0	0	-1.0	-10.3	+6.5	No change
Molythane 4615	2	+0.2	0	0	+1.5	-28.4*	+2.2	No change
	7	+0.4	0	0	-30.8	-24.9	+2.7	No change
Nitrile 112-82	2	-1.0	-0.8	0	-3.6	-14.2	+14.3	No change
	7	-1.5	-1.4	0	-5.0	-19.5	+12.3	No change
Nitrile 177-8	2	+0.2	-0.9	0	+17.6	-1.6	+23.2	No change
	7	+0.3	-1.3	+1.1	+12.8	-5.3	+16.6	No change
Nitrile 112-85	2	-1.4	-1.8	+2.4	+5.1	-15.3	+28.0	No change
	7	-2.0	-2.5	+1.2	+1.1	-21.5	+25.4	No change
Nitrile 162-2	2	-0.8	-0.5	+1.6	+3.6	-18.5	+34.4	No change
	7	-1.1	-2.2	+2.0	+1.2	-26.2	+34.5	No change
Nitrile 135-6	2	-0.7	-0.9	0	+4.0	-19.6	+28.8	No change
	7	-0.7	-1.2	+1.3	+6.1	-19.6	+26.9	No change

Table 13 Tests by MERL of various elastomers exposed to a buffered cesium / potassium formate brine at 181°C / 358°F.

Sample	Exposure time	Volume change [%]	Mass change [%]	Comment
PEEK®, split ring	9 days	0.10		No visible change
Viton® O-rings	2.2 days	-1.09		Stiff; surface cracks; fragments flaked off
Viton® O-rings (4 samples with different diameters)	1.5 days	~0.55		Stiff; surface cracks
NBR O-ring x- sect. diam. 6.5 mm	8.3 days	-0.10	-3.6	Hard; very stiff; volume change
Aflas® O-ring x- sect. diam. 6.5 mm	8.3 days	0.39	0.4	No change; remains flexible; no visible damage
Viton® ETP O-ring x- sect. diam. 6.5 mm	6.8 days	-0.10	0.3	No change; remains flexible; no visible damage
	2.1 days	0.03		Split in one place (perhaps result of cleaning), no other visible damage

Table 14 Property changes of elastomer samples exposed to a 2.18 s.g. buffered cesium formate brine (added 5% KCl) for 48 hours at 204°C / 400°F. The tests were carried out by Westport Technology Center International [12].

Sample	Weight change [%]	Volume change [%]	Hardness change [%]	Appearance change
CDI 904-90 FEPM	+0.3	0	-1.2	No change
	+0.3	0	-1.2	
	+0.3	+0.2	-1.2	
CDI 908 LS FKM	+2.4	+3.9	+5.7	Blistering, cracking and brittle
	+2.6	+3.2	+5.7	
	+3.1	+4.1	+5.7	
CDI 928 FKM	+2.5	+0.2	+1.1	No change, but brittle when bent

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