FKM Elastomer Coagents in the Oilfield Environment
A study of comparative changes in tensile strength after aging in Simulated Production Fluid

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Daniel L Hertz III

Campbell Dickson

Taylor Boyle

Seals Eastern Inc.

Red Bank, NJ, 07701

USA

ABSTRACT

FKM class elastomers have become essential sealing materials in the oilfield where thermal stability and/or chemical resistance are required. Proper material specifications sometimes establish FKM "Type" requirements. Absent an explicit material "Type" specification, meeting particular performance attributes and/or short-term aging requirements may determine the FKM Type by default. Unfortunately, specifications are frequently silent regarding the cure and coagent utilized (e.g. BPAF, TAIC, etc.) to vulcanize the FKM elastomer. This distinction should be important to the application engineer since FKM Types 1, 2, and 4 are available in either peroxide or BPAF cured grades.

This paper offers comparative data to analyze mechanical and aging differences between BPAF and peroxide/TAIC coagents for specific FKM Types after aging in a simulated oilfield production fluid.

INTRODUCTION

Background

FKM class elastomers are typically specified for sealing applications requiring specific

chemical resistance, thermal stability, or some combination thereof. Chemical

resistance is primarily a function of the polymer's molecular constitution and the cure

system. While chemical resistance data of the FKM class types is widely documented, far

less attention is paid to the cure system which can have significant impact on physical

property retention. Such distinctions are important in the oilfield where temperatures

are usually elevated (necessitating use of the fluoro-rubber in the first place) and

potential reactions are subsequently accelerated. In the FKM class of rubber, specifically

Type 1, Type 2 and Type 4 FKM's, seal application engineers have either the BPAF or

peroxide (w/TAIC) cure at their disposal.

The alternative cure to a BPAF cure is frequently specified as a "peroxide cure".

However, the peroxide cure requires a molecular coagent that serves in a similar

capacity as the BPAF molecule. TAIC is a more common coagent used in conjunction

with a peroxide initiator to effectively cure an elastomer. This paper uses the terms

peroxide and TAIC coagent interchangeably, even though they are different chemical

species serving a different purpose in the cure system.

Objective

Our primary objective was to provide data isolating performance attributes and aging characteristics of the BPAF cure and the TAIC cure within FKM class compositions.

The attributes examined were tensile strength, Young's modulus, and modulus at 50% strain ("M50") to draw conclusions regarding their relative stability in ISO Simulated Production Fluid

Scope

Elastomers:

This paper examined three of the FKM class of elastomers, as defined by ASTM D1418-01a.

Specifically,

> FKM – "Fluoro rubber of the polymethylene type that utilizes vinylidene fluoride as a comonomer …
> Type 1 – Dipolymer of hexafluoropropylene and vinylidene fluoride.
> Type 2 - Terpolymer of tetrafluoroethylene, vinylidene fluoride, and hexafluoropropylene.
> Type 4 – Terpolymer of tetrafluoroethylene, propylene and vinylidene fluoride.".

Type 3 was omitted from the study since it is only available as a peroxide cured material. Type 5 was omitted since there is only one variety on the market and it is peroxide cured.

Environment:

Crosslink stability of these two cure systems was examined across the three types of FKM after aging in a simulated production fluid (hereinafter "SPF") per ISO 23936-2:2011(E), specifically:

- a non-aromatic, sweet multi-phase fluid per A.1.i capped with nitrogen.

Aging was conducted at three temperatures: 165°C, 180°C, and 195°C.

Evaluation:

At its simplest level, an elastomer ages individually or through some combination of three basic mechanisms: chain scission, crosslink scission, and/or crosslink addition.

Kuhn developed an equation (Eq.1) for shear modulus that describes the effect of these mechanisms.[1]

$$G = NkT = \frac{\rho RT}{M_c} \tag{1}$$

Under this equation, shear modulus (G) is directly proportional to the number of polymer chains per unit volume (N) at a given temperature (T - Kelvin), where (k) equals Boltzmann's constant. Similarly, shear modulus is proportional to the material's density (ρ) at a given temperature and inversely proportional to the molecular weight between crosslinks (M_c) where (R) is the universal gas constant. One can quickly deduce that as crosslink density increases, modulus increases. Naturally, the molecular weight between crosslinks has decreased during crosslink addition.

Logically, the energy potential of an elastomer is better evaluated at low strains, staying within the linear region of the stress-strain curve. On a basic level, the modulus of a formulated elastomer will be a function of the elastomer's molecular constitution, the cross-link density, and the elastomer's interaction with a reinforcing filler. A reinforcing filler, such as carbon black, will affect an elastomer's modulus as a function of the filler's particle size, surface energy, and loading. As a general rule and holding all else constant (including particle structure), the smaller the particle size, the higher the modulus. Hertz, in his chapter on Sealing Technology[2], observed this logical increase in modulus as particle size decreased when evaluated using strain energy calculated at twenty percent strain. This relationship, however, failed when stress was examined at strains exceeding 100%, presumably due to rupture at the polymer-filler interface. Arguably, at high strain, polymer-filler interactions become increasingly complex and unpredictable as

[1] Hertz, Jr., Daniel, "Sealing Technology", Rubber Products Manufacturing Technology, p.790, Marcel Dekker, Inc. (1994).
[2] Hertz, Jr., Daniel, "Sealing Technology", Rubber Products Manufacturing Technology, p.781, Marcel Dekker, Inc. (1994).

reflected in the broad range of measured stress values. Specifically, the standard deviation of stress data points is increasingly larger as strain increases. Nevertheless, subject to this important caveat, the authors included "tensile at break" data in the analysis. Old habits do in fact die hard.

EXPERIMENTAL

Six commercially available fluoroelastomer base polymers were selected, based upon their class and recommended cure systems. The test materials are differentiated by FKM type and cure as tabulated below. A uniform carbon black reinforcement (i.e. 30 phr of N990) was used in all instances. TAIC was used as the coagent in the peroxide cure materials. Polymer manufacturers frequently utilize incorporated cures: such instances have been noted herein. Similarly, manufactures frequently incorporate cure-site monomers susceptible to the peroxide: these instances are noted as well.

FKM Type	Cure	Product Grade	Supplier	Brand
1	Peroxide	*FE 2260*	3M	Dyneon[3]
1	Bisphenol	*FE 5620 Q*	3M	Dyneon™
2	Peroxide	*P 959*	Solvay	Tecnoflon[4]
2	Bisphenol	*FOR 4391*	Solvay	Tecnoflon
4	Peroxide	*200P*	Asahi Glass	Aflas®[5]
4	Bisphenol	*BRE 7231*	3M	Dyneon

Table 1: FKM Type elastomers used in the study

Tensile testing and percent swell were chosen as key indicators to track chemical interaction/degradation of the experimental FKM compounds. Dumbbells cut in accordance with ASTM D412 and rectangular specimens were immersed in the SPF in stainless steel aging vessels.

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[3] Dyneon™ is a trademark of 3M.
[4] Tecnoflon is a trademark of Solvay.
[5] Aflas® is a registered trademark of Asahi Glass Co.

The aging vessels were purged with ultra-high purity nitrogen gas and incubated at 165°C, 180°C, and 195°C. The compounds were equilibrated at each temperature for 48 hours to establish baseline properties, and subsequently aged for 168, 336, and 504 hours at each temperature. Three dumbbells and one rectangular coupon were subjected to this protocol for each combination of compound, temperature, and aging time.

Specific gravity was measured and tracked before and after aging to allow calculation of percent swell[6]. Dumbbells were subjected to tensile testing using an Instron.

Experiment Variables are presented in Table 2.

Aging period	• 168 hours (1 week) • 336 hours (2 weeks) • 504 hours (3 weeks)
Test Specimen	• DMRT bar • D412 dumbbells3 (3 per test material)
Test Fluid	• Non-aromatic: 70 % heptane, 30 % cyclohexane
Multi-phase	• 30% Nitrogen, 10% water, 60% fluid
Test Temperatures	• 165°C • 180°C • 195°C

Table 2: Experiment test matrix

Methodology

Our experiment was geared towards understanding the difference, if any, in the relative stability of BPAF and TAIC in ISO 23936-2 simulated production fluid ("SPF") at different operating temperatures. A fundamental premise is that the thermal stability of the cure system and/or elastomer will be reflected by changes in the elastic modulus of the vulcanizate as molecular weight between crosslinks either increases or decreases.

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[6] Per ASTM D471-12a (2013).

The same filler was used in the six formulations and a best effort was made to develop an approximately equal crosslink density with the objective of isolating the crosslink as one variable and the elastomer backbone as the other variable. Obviously, the differences in molecular constitution of BPAF and TAIC, respectively bi-functional and tri-functional, will tend to deliver different properties, thus we focused on relative changes in attribute retention to draw conclusions.

Aging was accomplished by immersing test specimens in steel cylindrical test vessels containing the multi-phase test media (see Table 3). The test vessels were then aged in a conventional convection oven.

Liquid Phase (% Volume)	Gas Phase (% Volume)	Composition
–	30	Nitrogen (N_2)
10	–	Deionized Water
60	–	70% Heptane, 30% cyclohexane

Table 3: Composition of ISO simulated production fluid (SPF). See ISO 23936-2 section A.1.1.2

Methodology for Arrhenius Analysis:

Arrhenius analysis allows prediction of rubber lifetimes by assuming the complicated thermal degradation reaction has the overall behavior of a 1st-order reaction. Such a situation can occur if a complex reaction mechanism has a single rate-limiting step so that the reaction rate of this step dominates the reaction kinetics. If the current percent conversion of the polymer chain to degraded product is α, then the conversion rate of a 1st-order process can be described as follows:

$$\frac{d\alpha}{dt} = k(T)f(\alpha) \qquad (2)$$

Equation 2 describes the change in conversion rate as a product of the reaction rate (k(T)) and the amount of reactant left (f(α)). If we assume that the reaction is first order, then the temperature-

dependent reaction rate dominates the rate at which the polymer thermally degrades. The impact of temperature on the process rate of a reaction is described by the Arrhenius equation:

$$k(T) \ \propto \ Ae^{\frac{-E_a}{RT}} \qquad (3)$$

In equation 3, T stands for absolute temperature, A and E_a refer to the preexponential factor and activation energy (polymer-specific kinetic parameters) and R is the gas constant. Intuitively, it states that a reaction's rate increases exponentially with increasing temperature.

The predictive power of equation 3 comes from the assumption of a first-order reaction. The following equation relating reaction rate (k) and reaction time (t) to conversion percentage holds for first-order reactions:

$$\ln\left(\frac{[reactant]}{[product]}\right) = kt \qquad (4)$$

Using the above relation and assuming physical properties act as a proxy to measure reaction progress, we are looking for the point when tensile at break ("TAB") is equal to some proportion, p, of the baseline tensile at break. Thus, the variable concentrations cancel in equation 4, giving us the relationship below:
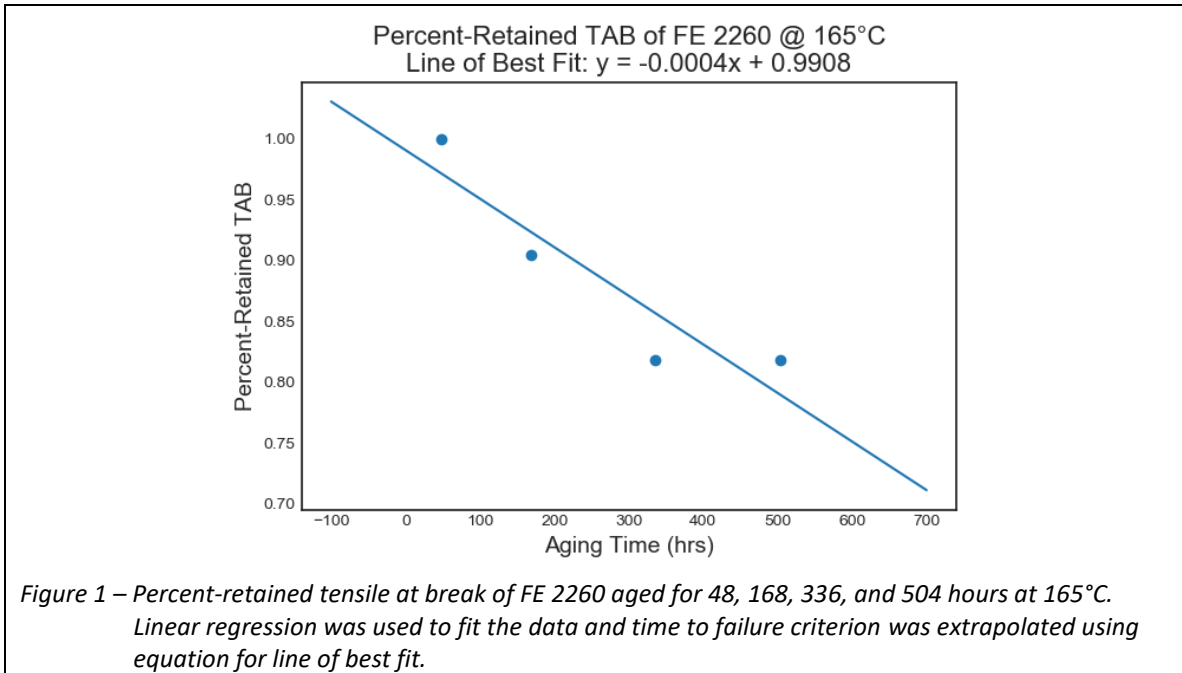
$$kt_{failure} = constant \qquad (5)$$

Taking equations 3 and 5 into consideration, we can relate the failure time to the temperature and aging time of a rubber compound with the following relation:
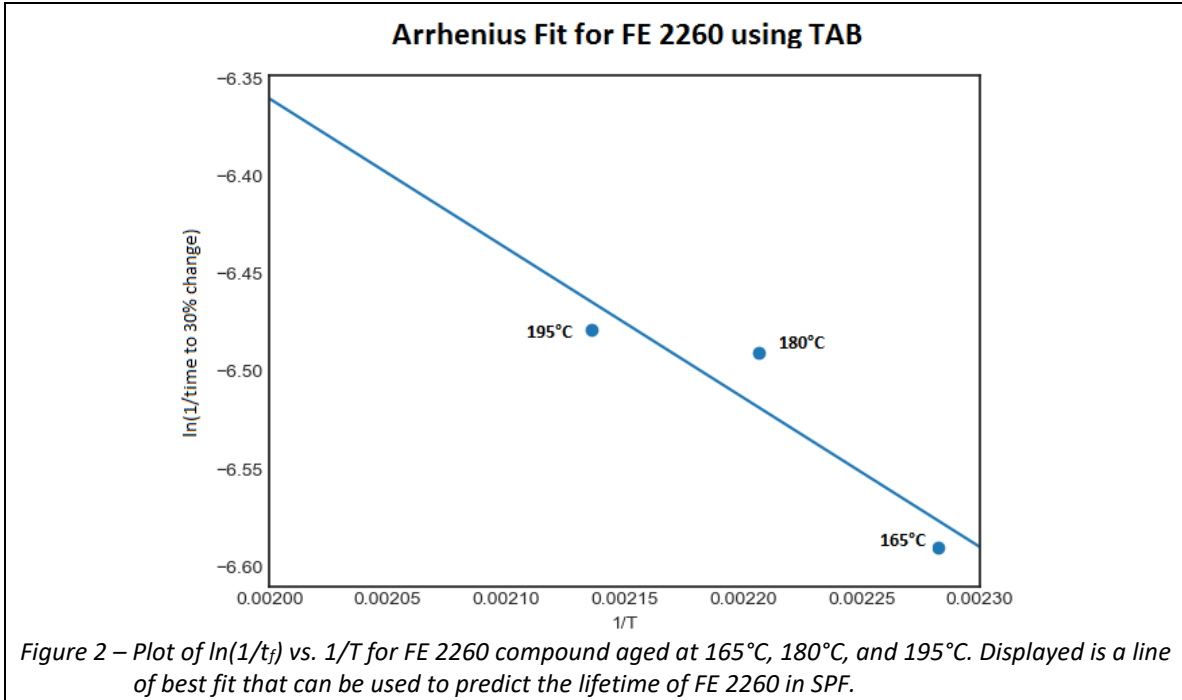
$$\ln\left(\frac{1}{t_f}\right) = \ -\frac{E_a}{R} * \left(\frac{1}{T}\right) + constant \qquad (6)$$

A brief example of modeling thermal degradation using an Arrhenius fit follows (using TAB for the compound FE 2260). Figure 1 details the procedure used to estimate t_f for a given compound, property, and temperature. The same linear regression process was completed

using TAB data for each compound and each temperature. If ASTM D2000 section IV

methodology is considered, a rubber is deemed unsuitable for a service type (heat) when TAB

has reached ±30% of its original value. The authors deemed this to be a failure point for

purposes of Arrhenius life prediction.

Figure 1 – Percent-retained tensile at break of FE 2260 aged for 48, 168, 336, and 504 hours at 165°C.
Linear regression was used to fit the data and time to failure criterion was extrapolated using
equation for line of best fit.

This procedure gives three values of t_f for the three temperatures at which the compounds were

tested, allowing creation of a graph like the one shown in Figure 2 below.

Figure 2 – Plot of ln(1/t_f) vs. 1/T for FE 2260 compound aged at 165°C, 180°C, and 195°C. Displayed is a line of best fit that can be used to predict the lifetime of FE 2260 in SPF.

Yet another linear regression provides an equation with which the lifetime of a compound at various temperatures can be predicted using the following equation, where T is the desired temperature, and m and b are the slope and y-intercept, respectively, of the line of best fit:

$$t_f \approx e^{-(\frac{m}{T}+b)} \tag{7}$$

Methodology for Analysis of Variance (ANOVA):

ANOVA is a statistical technique used to infer significant differences between three or more population means based on the variances of samples drawn from each population. As such, it is a generalization of the t-test that is very powerful for analyzing the impact of independent factors on dependent variables. ANOVA can be further extended to study the relationship of multiple such factors with a dependent variable (known as an n-way ANOVA, where n is the number of factors).

In this case, the aim is to study how the FKM type and cure package influence the kinetics of thermal degradation for a fluoroelastomer rubber. Thus, six different "treatments" are

developed which correspond to each possible combination of the two different factors (see below).

Independent Factor	*Peroxide*	*BPAF*
Type 1	FE 2260	FE 5620
Type 2	Tecnoflon P 959	Tecnoflon FOR 4391
Type 3	AFLAS 200 P	BRE 7231

Table 4 – Breakdown of experimental treatments for the ANOVA conducted in this experiment.

A few criteria must be met for the results to be valid: compounds must be identical except for their "treatment" and the assumptions of an ANOVA must be met, specifically the populations are normally distributed and homoscedastic[7]. Means and variances are calculated for each individual treatment group as well as for each independent factor group. For this example, mean and variance would be calculated for each compound, all the type 1, 2, and 4 FKMs grouped together, and the peroxide and BPAF-cured samples grouped together respectively. This provides parameters with which the presumed distribution of each population can be compared to one another.

An ANOVA's null hypothesis is that the distribution of each of the treatment groups is statistically unchanged. Hypothesis testing proceeds similarly to a pairwise t-test for each combination of treatment groups. The main difference for an ANOVA is a correction for the significance level of each hypothesis test, due to an increased risk of a type II[8] error. Further, the data are modeled using an F-distribution and an F-test is used for hypothesis testing.

The results of an ANOVA tell the researcher whether the treatment group distributions are impacted by any of the independent factors. Additionally, an n-way ANOVA can uncover

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[7] Homogeneity of variance.
[8] Failing to reject a false null hypothesis (also known as a "false negative" finding).

interaction effects between multiple independent factors. This makes it an attractive technique

for understanding how a complex process can be put under statistical control. It is important to

note, however, that the ANOVA's resolution is not perfect. For example, it cannot discern which

FKM type is best for chemical resistance. Instead, it alerts the researcher only to the fact that

FKM type does or does not significantly affect chemical resistance. To obtain higher "resolution"

in results, it is required to conduct post-hoc analyses that allow the characteristics of the

population distributions to be compared to one another.

As a final note, all statistical analyses conducted in this paper were calculated using Microsoft

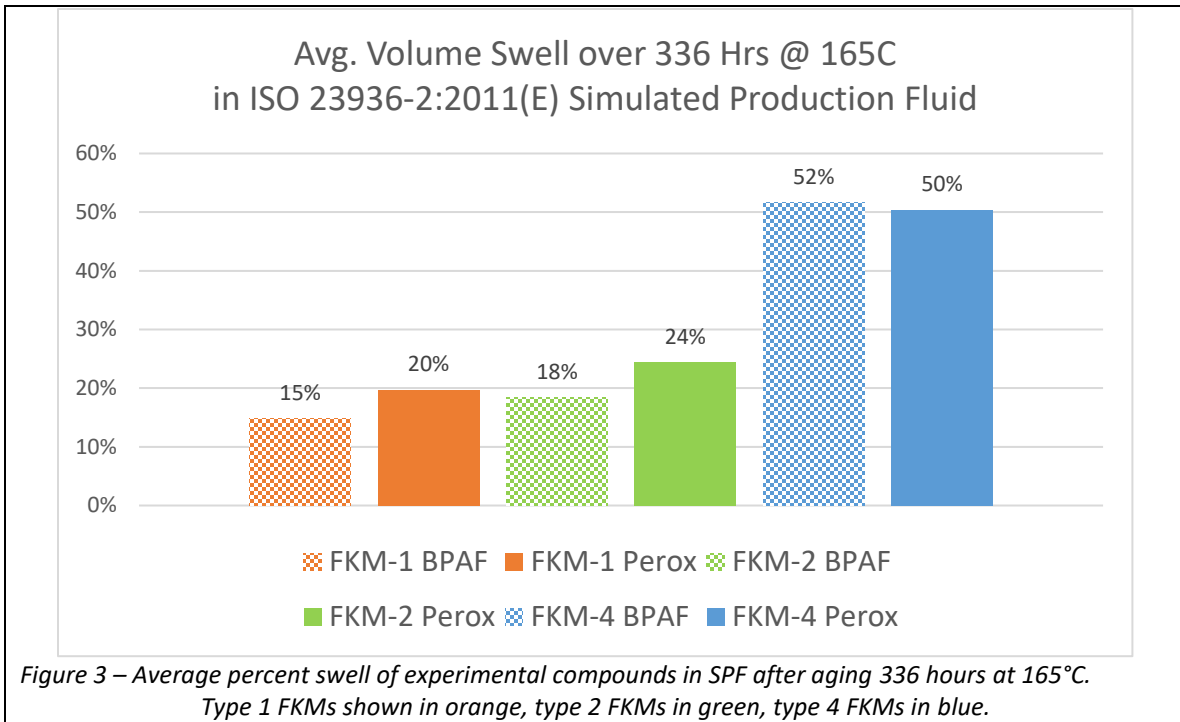Excel 2016 with the Data Analysis toolpack[9].

RESULTS AND DISCUSSION

1. Percent Swell of Compounds Aged in SPF

The percent swell of each compound in the SPF was measured since it is an important

determinant of compound suitability in an oilfield environment. A large quantity of swell data

was collected during the study; a representative sample that accurately captures the behavior of

the experimental compounds in SPF is reproduced below in Figure 3.

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[9] Formulas used for calculating distribution parameters and test statistics can be found in the documentation for Excel's Data Analysis toolpack.

Figure 3 – Average percent swell of experimental compounds in SPF after aging 336 hours at 165°C. Type 1 FKMs shown in orange, type 2 FKMs in green, type 4 FKMs in blue.

A noteworthy observation is the severe swelling of type 4 FKMs in the SPF. Regardless of cure package, these samples had double the volume increase of other FKM types. It is likely that the propylene monomer included in type 4 FKM polymers increases solubility for the alkanes comprising the SPF. In light of the high swelling, the authors consider type 4 FKMs to be unsuitable for sealing service in high aliphatic content oilfield environments unless of course high swelling is a desirable attribute. The difficulty of collecting valid modulus data on account of such swelling forced the authors to exclude Type 4 results from some of the analysis in the following sections.

The type 1 and type 2 FKMs swelled less than 25 percent during extended exposure in SPF. Interestingly, it appears that the type 1 FKMs swell slightly less than the type 2 samples. This is counterintuitive as type 2 FKMs have higher fluorine content and are generally considered to have better fluid resistance, however, the result may be attributed to noisy data. Lower percent swell amongst BPAF-cured type 1 and type 2 FKMs is also noticeable when compared to the peroxide-cured samples. It is possible the fluoro-methyl groups associated with the BPAF

14

molecule help retard aliphatic alkane absorption. The least speculative conclusion that can be construed from the data is that type 1 and type 2 FKMs resist swell to a very similar degree in SPF, regardless of cure.

2. Arrhenius Lifetime Estimates from Tensile Degradation

The type 1 and type 2 FKM compounds were subjected to Arrhenius analysis for a variety of physical properties. Of the properties collected with the Instron™, percent-retained TAB conformed most closely to an Arrhenius model and thus was used to compare compound lifetime estimates. It was assumed that a 30% reduction in TAB constituted failure. The results of this analysis are recorded in Table 5 below.

Type, Cure	Grade	Arrhenius Model	Lifetime (hrs) @ 150°C	Lifetime (hrs) @ 210°C
Type 1, TAIC cure	*FE 2260*	y = -766x - 4.828	764	612
Type 1, BPAF cure	*FE 5620 Q*	y = -3492x + 0.221	3,076	1,105
Type 2, TAIC cure	*P 959*	y = -2184x - 1.560	830	437
Type 2, BPAF cure	*FOR 4391*	y = -10250x + 15.766	4,708	232

Table 5 – Lifetime predictions for FKM type 1 and type 2 at 150°C and 210°C service temperatures.

Lifetime predictions were compared for hypothetical 150°C and 210°C operating temperatures. Such a large temperature spread highlights differences in reaction kinetics between the compounds. For instance, a Type 2, BPAF cure has the shortest lifetime at the relatively high temperature of 210°C but the highest lifetime at the lower end temperature of 150°C. The stability of a Type 1 TAIC cure, by contrast, is least impacted by aging in a temperature range of 150°C to 210°C, suggesting it is a better choice for service conditions with broad operating temperatures.

More generally, it appears that the type 1 FKMs are more stable at high temperatures while type 2 FKMs last longer at lower temperatures. This could be attributable to a higher percentage of HFP in the backbone of Type 1 (as compared to a Type 2 FKM) increasing steric hindrance and

potentially reducing polymer chain scission. Additionally, it appears there is a tendency of the BPAF-cure withstanding thermal degradation better than peroxide cure when aged in in SPF. This could be explained by the relatively bulky fluoro-methyl groups of the BPAF coagent, whose steric hindrance might better shield the cross-link from oxidative reactions in the SPF fluid.

3. Analysis of Variance ("ANOVA") between FKM type and Cure Package

To more directly weigh the interaction of FKM type and cure package with the long-term thermal degradation of elastomer properties, a two-way ANOVA was conducted for each compound at each temperature. In this case, the ANOVA is equivalent to testing the following null hypothesis:

$$\mathbf{H_0}: \quad \mu_{\text{Peroxide}}^{\text{Type 1}} = \mu_{\text{BPAF}}^{\text{Type 1}} = \mu_{\text{Peroxide}}^{\text{Type 2}} = \mu_{\text{BPAF}}^{\text{Type 2}} = \mu_{\text{Peroxide}}^{\text{Type 4}} = \mu_{\text{BPAF}}^{\text{Type 4}}$$

Clearly chemical resistance will vary across the different FKM types, as the polymer composition changes between FKM types. ANOVA is helpful, however, in discerning the impact that the selected cure package has on thermal degradation resistance. Furthermore, ANOVA can delineate significant interaction effects between FKM type and cure package. Table 6 below shows the distribution of percent-retained TAB for each of the compounds after 504 hours at 180°C, segregated by FKM type and cure package.

Type 1 FKMs	Peroxide	BPAF	Total
Average	0.757	0.930	0.844
Variance	0.006	0.001	0.012
Type 2 FKMs	Peroxide	BPAF	Total
Average	0.784	0.874	0.829
Variance	0.003	0.001	0.004
Type 4 FKMs	Peroxide	BPAF	Total
Average	0.719	0.788	0.754
Variance	0.001	0.00001	0.002

Table 6 – Distributions of percent-retained TAB at 180°C within and between the test factors (FKM type and cure package). Depicts average and variance for each test group.

Table 6 reveals some interesting trends. It suggests that type 1 FKMs generally have the greatest

resistance to SPF, followed closely by the type 2 FKMs, with the type 4 FKMs performing the

worst. This matches qualitative observations of sample degradation, the trends observable in

percent-swell data (see *Figure 3*), and it reflects the predictions of the Arrhenius models at

higher temperatures (see *Table 5*). Again, it is obvious that FKM type influences aging in SPF due

to their significant differences in polymer composition. The next question is whether the cure

type asserts influence upon aging in SPF. Consider the results of the two-way ANOVA that are

collated in *Table 7* below.

Source of Variation	SS	df	MS	F	P-value	F crit
FKM Type	0.028	2	0.014	7.145	0.009	3.885
Cure Package	0.055	1	0.055	27.927	0.0002	4.747
Interaction	0.009	2	0.004	2.281	0.145	3.885

Table 7 – Results of a two-way ANOVA of percent-retained TAB after 504 hours at 180°C for each of the experimental compounds.

It appears that both FKM type and cure package significantly impact the lifetime of the rubber

(p=0.009 and p=0.0002, respectively). This result speaks to the primary objective of the

experiment; it appears that, even within a specific FKM type, the choice of cure package is an

important consideration if tensile retention is critical to a sealing application in hot aliphatic

hydrocarbons. The lack of a significant interaction effect suggests that this reliance of SPF

resistance on cure package is independent of the FKM type. A two-sample t-test was conducted

as a post-hoc analysis to determine the nature of the cure package's relationship with SPF

resistance (*Table 8*).

	Peroxide	BPAF
Mean	0.75	0.86
95% CI	0.710-0.797	0.813-0.915
Variance	0.00324	0.00434
p-value	0.00078	

Cohen's Effect Size (d)	*1.79*

Table 8 – Results of a one-tailed, two-sample t-test of sample means for peroxide- and BPAF-cured FKM samples.

It is evident that the BPAF-cured samples resisted tensile aging to a substantially higher degree than the peroxide-cured samples (p=0.00078). A 95% confidence interval ("CI") for the two sample means puts the true average degradation of peroxide-cured samples between 71.0% and 79.7%, while BPAF-cured samples have a 95% CI of 81.3% to 91.5%. The lack of overlap strengthens certainty in the significant difference uncovered by the t-test.

The width of the two confidence intervals, on the other hand, makes it difficult to talk about the long-term SPF resistance benefits of a certain cure package. It is likely that this wide spread is a consequence of low statistical power resulting from small sample sizes. However, it is possible that the unpredictable (or noisy) nature of rubber could hinder precision in population estimates even with a larger sample size. Instead, the reader could consider the confidence intervals as general limitations for ultimate tensile performance in high temperature, oilfield environments. Further, it appears that the increase in aging resistance correlated with use of a BPAF cure is quite substantial. An effect size measure was calculated (Cohen's effect size) to estimate the magnitude of the cure package effect on aging resistance. The calculated value is 1.79, a high value for such an effect size measure. This suggests that incorporating a BPAF cure reduces the thermal degradation of the rubber's TAB by an average of 1.79 standard deviations, relative to the distribution for peroxide cured rubbers.

SUMMARY

ISO's SPF simulates a mixed solvent system (water, short chain alkanes, cycloalkanes) frequently encountered in the oilfield. Seals employed in oil wells must be strong and

resilient but, more importantly, must resist the degradation of physical properties attributable to high operating temperatures in water and aliphatic hydrocarbons. Rubber is not a simple, predictable material but instead a complex, dynamical system of interacting components: the polymer, its cure system, and its reinforcement. Mathematical and statistical modeling can be important techniques in understanding how rubber can be expected to behave in various sealing applications.

This experiment utilized popular statistical techniques to characterize the impact of FKM type and cure package on the resistance of a fluorocarbon rubber to ISO simulated production fluid (see Table 3 *supra*). Despite the aggressive nature of SPF and noisy property measurements, several unequivocal results were obtained in this study:

First, the data contra-indicates using type 4 FKMs in a hot aliphatic rich oilfield environment since they swell and lose their tensile strength too quickly.

Second, BPAF cures appear to retain tensile property longer than peroxide cure in a hot aliphatic rich fluid.

Third, Type 1 FKMs appear more thermally stable than Type 2 when temperatures approach 210C.

Fourth, type 2 FKMs exhibit better tensile retention at temperatures of 150C and below.

Finally, in a hot (150C+) environment that could be characterized similar to that of ISO's SPF, a BPAF cure is generally preferable to a peroxide cure.

APPENDIX

FKM Type 1 test material compositions:

BPAF Cure			Peroxide-TAIC Cure		
Constituent	PHR		Constituent	PHR	
Dyneon FE5620	100		Dyneon FE2260	100	
MT Black (N990)	30		MT Black (N990)	30	
Bisphenol Onium (incorporated)	--		Triallyl isocyanurate (TAIC)	2.5	
MgO	3		Peroxide (VAROX DBPH-50)	2.5	
Calcium Hydroxide	6		Calcium Hydroxide	3	
Table A1			Table A2		

FKM Type 2 test material compositions:

BPAF Cure			Peroxide-TAIC Cure		
Constituent	PHR		Constituent	PHR	
Tecnoflon FOR 4391	100		Tecnoflon P 959	100	
MT Black (N990)	30		MT Black (N990)	30	
Bisphenol Onium (incorporated)	--		Triallyl isocyanurate (TAIC)	4	
MgO	3		Peroxide (Luperox 101XL-45)	3	
Calcium Hydroxide	6		ZnO	5	
Table A3			Table A4		

FKM Type 4 test material compositions:

BPAF Cure			Peroxide-TAIC Cure		
Constituent	PHR		Constituent	PHR	
BRE 7231	100		Aflas 200 P	100	
MT Black (N990)	30		MT Black (N990)	30	
Bisphenol Onium (incorporated)	--		Triallyl isocyanurate (TAIC)	5	
MgO	9		Peroxide (?)	1	
Struktol WS-280	2		Sodium Stearate	1	
Table A5			Table A6		