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TECHNICAL MEMORANDUM 98/229  
September 1998

**Evaluation of the Chemical Resistance of  
Epichlorohydrin and Fluorocarbon Elastomers to  
Hydrocarbon Fill Fluids**

John A. Hiltz and Irvin A. Keough

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## Evaluation of the Chemical Resistance of Epichlorohydrin and Fluorocarbon Elastomers to Hydrocarbon Fill Fluids

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Approved by R. M. Morchat:  
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## Abstract

The chemical resistance of an epichlorohydrin elastomer and three fluorocarbon elastomers to Bayol 35, Voltesso 35, and Marcol 72 hydrocarbon fill fluids has been investigated. Absorption of fill fluid and the resulting change in the glass transition temperature were used to evaluate the chemical resistance of the elastomers. The weight change of the fluorocarbon elastomers was less than 0.1% by weight indicating that these elastomers have excellent chemical resistance to the fluids. The epichlorohydrin elastomer absorbed approximately 0.6% Bayol 35, 2.0% Voltesso 35, and 3.25% Marcol 72 and the  $T_g$  of the epichlorohydrin elastomer decreased slightly following immersion in the fill fluids. This elastomer has good to excellent resistance to the fill fluids. The  $T_g$  of the four elastomers studied here are high enough to cause concern about these elastomers undergoing a rubber to glass transition in low temperature, high frequency applications. Epichlorohydrin based copolymer or terpolymer elastomers have lower  $T_g$ s and should remain rubbery at low temperature and higher frequencies. Evaluation of these elastomers is warranted.

## Résumé

On a étudié la résistance chimique d'un élastomère d'épichlorhydrine et de trois élastomères à base d'un fluorocarbure, aux liquides de remplissage à base d'hydrocarbure Bayol 35, Voltesso 35 et Marcol 72. On a évalué la résistance chimique des élastomères à partir de l'absorption du liquide de remplissage et de la variation de température de transition vitreuse qu'elle entraînait. Les élastomères à base d'un fluorocarbure accusaient une variation de masse inférieure à 0,1 % en poids ; ils possèdent donc une excellente résistance chimique aux liquides. L'élastomère d'épichlorhydrine absorbait environ 0,6 % de Bayol 35, 2,0 % de Voltesso 35 et 3,25 % de Marcol 72, et sa  $T_g$  diminuait légèrement après immersion dans les liquides de remplissage. Cet élastomère possède une résistance aux liquides de remplissage allant de bonne à excellente. La  $T_g$  des quatre élastomères étudiés dans cette communication est suffisamment élevée pour que ces élastomères subissent une transition caoutchouc-verre lors d'applications à basse température et à haute fréquence. Les élastomères d'épichlorhydrine copolymériques ou terpolymériques possèdent des  $T_g$  plus faibles et devraient conserver leur nature caoutchouteuse lors d'applications à basse température et à haute fréquence. Il y a lieu de procéder à une évaluation de ces élastomères.

DREA TM/98/229

**Evaluation of the Chemical Resistance of Epichlorohydrin and Fluorocarbon Elastomers to Hydrocarbon Fill Fluids**

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**EXECUTIVE SUMMARY**

**Introduction**

An elastomeric boot is used to prevent ingress of the hydrocarbon fill (buoyancy) fluids into towed array barrel stave projectors. The original boot material, 5109S neoprene rubber, failed in service. Experimentation indicated that this elastomer did not have the required chemical resistance to hydrocarbon based fill fluids. This led to swelling and eventual failure of the boot. To prevent further boot failures, an elastomer with better chemical resistance to the fill fluid was required.

In this memorandum, the chemical resistance of an epichlorohydrin and three fluorocarbon elastomers to three hydrocarbon fill fluids, Bayol 35, Voltesso 35, and Marcol 72, are investigated. These elastomers were selected for evaluation because the literature reports that they have excellent resistance to hydrocarbons.

**Principal Results**

Fluid absorption and changes in the dynamic mechanical properties of the elastomers in contact with the fluids were used to evaluate the chemical resistance of each of the elastomers to three fill fluids.

The epichlorohydrin elastomer absorbed approximately 0.6% Bayol 35, 2.0% Voltesso 35, and 3.25% Marcol 72 and the  $T_g$  of the epichlorohydrin elastomer decreased slightly following immersion in the fill fluids. This elastomer has excellent resistance to Bayol 35 fill fluid and good to excellent resistance to Voltesso 35 and Marcol 72 fill fluid. The fluorocarbon elastomers have excellent chemical resistance to the fill fluids. The weight change of the fluorocarbon elastomers was less than 0.1% by weight and  $T_g$  changed very little following immersion in the fluids.

However, the  $T_g$ s of four elastomers were high enough to cause concerns about the elastomers performance in low temperature, high frequency applications. In the area of the glass transition  $\tan \delta$  goes through a maximum. As transmission of acoustic energy decreases with an increase in  $\tan \delta$ , this will adversely affect performance of the system. Also the elastomer may become glasslike and fail.

**Significance of the Results**

Although the four elastomers have good chemical resistance to hydrocarbon based fill fluids, dynamic mechanical analysis indicated that these elastomers will not perform as desired at lower temperatures and higher frequencies.

**Future Plans**

Epichlorohydrin based copolymer or terpolymer elastomers will be evaluated. These elastomers have lower  $T_g$ s. Problems associated with the elastomers approaching the glass transition region under service conditions should be eliminated.

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## **1.0 Introduction**

The selection of a polymeric material for a particular application will depend on the in-service conditions. One of the most important in-service conditions is the chemical environment. Interaction between a polymer and its environment can alter the properties of the polymer. For instance, when a polymer is immersed in a fluid, absorption of the fluid can result in swelling, a reduction in tensile strength and modulus, an increase in elongation at break, and a decrease in the glass transition temperature ( $T_g$ ) of a polymer. The fluid may also leach additives, such as plasticizers, from a polymer. Loss of a plasticizer can result in an increase in tensile strength and modulus, a decrease in elongation at break, and an increase in  $T_g$  of the polymer. These changes are critical in applications where dimensional stability, hardness, mechanical and dynamic mechanical properties of the polymer are altered.

The failure of the outer elastomeric boot used on barrel stave projectors is an example of in-service degradation of a polymer resulting from its chemical environment. The boot, designed to prevent ingress of liquids into the projector, was fabricated using a neoprene rubber, designated 5109S. For seawater applications, the 5109S neoprene rubber boot performed well. However, the 5109S neoprene boot failed when the barrel stave projectors were deployed in a towed array system containing a hydrocarbon based buoyancy fluid. Absorption of the fill fluid caused the boot to swell. The boot then ruptured when pinched between adjacent staves of the projector.

This problem can be solved in one of two ways; replace the fill fluid with one that does not attack the boot material, or make the boot from an elastomer that is not attacked by hydrocarbon fill fluids. Because the fill fluids had properties that made them suitable for the application, it was decided to evaluate alternative boot materials. In particular, elastomers that were reported to have excellent resistance to hydrocarbon based fluids.

A previous report<sup>1</sup> compared the chemical resistance and dynamic mechanical properties of 5109S neoprene rubber and a fluorocarbon elastomer, QXA 3770. The fluorocarbon

elastomer had excellent resistance to hydrocarbon fill fluids. However, the glass transition temperature of this elastomer was high enough to cause concern about its performance under service conditions. Therefore, it was necessary to investigate other elastomers to determine if they had the required chemical resistance and dynamic mechanical properties for this application.

Four elastomers, three fluorocarbon-based materials and an epichlorohydrin, were selected for analysis on the basis of their reported chemical resistance to hydrocarbon fluids. The chemical resistance of the epichlorohydrin and fluorocarbon elastomers was assessed in two ways, immersion testing and monitoring of changes in the dynamic mechanical properties of the elastomers resulting from exposure to the fluids. Immersion testing involved monitoring absorption of the fluid (weight gain) by the elastomer as a function of time. The rate of diffusion of the fluid into the elastomer and weight of fluid absorbed by the elastomer give an indication of the resistance of the elastomer to the fluid. The dynamic mechanical properties, that is, storage modulus ( $E'$ ), loss modulus ( $E''$ ), and  $\tan \delta$  ( $E''/E'$ ), of an elastomer are all affected by the absorption of a fluid. Loss of an additive, such as a plasticizer will also affect the dynamic mechanical response of an elastomer. Changes in the magnitude and temperature of the maximum value  $E''$  and  $\tan \delta$  can be correlated with fluid absorption or plasticizer loss and can be used to assess chemical resistance of the elastomers.

## **2.0 Experimental**

### **2.1 Fluids**

Three hydrocarbon fluids, Bayol 35, Voltesso 35, and Marcol 72, manufactured by Imperial Oil, Toronto, Ontario were used in the chemical resistance testing of the elastomers. These fluids are used in towed array applications where neutral buoyancy is required. The viscosity of these fluids also facilitates their use. They are easy to pour and problems arising from entrapped air are minimized.



Bayol 35 is described<sup>2</sup> as a mineral oil consisting of a mixture of paraffinic and/or naphthenic hydrocarbons. Paraffinic refers to straight chain saturated hydrocarbons, while naphthenic refers to cyclic saturated hydrocarbons. It is reported to have a viscosity of 3.42 centistokes (cSt) at 25°C, a boiling range from 205°C to 255°C, and a density of 0.79 g/cc at 15°C.

Voltesso 35 is described<sup>3</sup> as a lubricating oil consisting of a mixture of saturated and unsaturated hydrocarbons derived from naphthenic distillate and distillates. It is reported to have a viscosity of 8.00 cSt at 40°C, a boiling range from 229°C to 444°C, a freezing pour point of -51°C, and a density of 0.87 g/cc at 15°C.

Marcol 72 is described<sup>4</sup> as a white mineral oil that consists of a mixture of naphthenic hydrocarbons. It is reported to have a viscosity of 12.40 cSt at 40°C, a boiling point of 230°C, a freezing pour point of -9°C, and a density of 0.84 g/cc at 15°C.

## 2.2 Rubbers

### 2.2.1 Epichlorohydrin Elastomer

The epichlorohydrin elastomer was prepared by M. A. Hanna Rubber Compounding, Tillsonburg, Ontario. The composition of the elastomer, referred to as Hydrin 45, is listed in Table 1.

**Table 1**

Chemical composition of the epichlorohydrin elastomer denoted as Hydrin 45.

Component	Parts per Hundred (PHR)
Hydrin H-45	100
HAF N-330	50.0
Stearic Acid	1.0
E(NBC ) D-70	2.9
ERD-90	5.6
END-75	2.0

The epichlorohydrin resin, Hydrin H-45, was obtained from Goodrich Canada, Waterloo, Ontario.

### 2.2.2 Fluorocarbon Elastomers

Three fluorocarbon elastomers were investigated. The elastomers, referred to as Material #2, Material #3 and Material #4, were prepared by M. A. Hanna Rubber Compounding, Tillsonburg, Ontario. Material #2 and Material #3 had Shore Durometer A hardnesses of 62 +/- 1, while Material #4 had a Shore Durometer A of 66 +/- 1. The compositions of the rubbers are listed in Table 2.

The Fluorel resins, FE-5642Q, FC-2179, FE-5840Q, FC-2178 and FC-2172, were obtained from 3M Canada.

FE-5642Q is a dipolymer of vinylidene fluoride and hexafluoropropylene containing 65.9% fluorine by weight. It is a 'Molded Goods Incorporated Cure Grade' polymer.

FC-2179 is a dipolymer of vinylidene fluoride and hexafluoropropylene containing 65.9% fluorine by weight. It is an 'O-ring Grade Incorporated Cure' polymer.

FE-5840Q is a terpolymer of vinylidene fluoride, hexafluoropropylene, and tetrafluoroethylene containing 70.2% fluorine by weight. It is an 'O-ring Grade Incorporated Cure Grade' polymer.

FC-2178 is a dipolymer of vinylidene fluoride and hexafluoropropylene containing 65.9% fluorine. It is a raw gum used to increase viscosity and green strength of incorporated cure grade Fluorel resins.

FE-2172 is a dipolymer of vinylidene fluoride and hexafluoropropylene containing 65.9% fluorine by weight. It is an incorporated cure grade polymer.

**Table 2**

Chemical composition of the fluorocarbon elastomers denoted as Material #2, Material#3, and Material #4.

**Material #2**

Component	Parts per Hundred (PHR)
FE 5642Q	75
FC-2178	25
FC-2172	1
N326 Black	4
N754 Black	6
MgO	3
Ca(OH) <sub>2</sub>	6

**Material #3**

Component	Parts per Hundred (PHR)
FC-2179	75
FC-2178	25
FC-2172	1
N326 Black	4
N754 Black	6
MgO	3
Ca(OH) <sub>2</sub>	6

**Material #4**

Component	Parts per Hundred (PHR)
FE-5840Q	75
FE-2178	25
FE-2172	1
N326 Black	4
N754 Black	6
MgO	3
Ca(OH) <sub>2</sub>	6

### **2.3 Fluid Exposure**

Rubber samples were immersed in Bayol 35, Voltesso 35, and Marcol 72 and weight changes monitored with time. Excess fluid on the surface of the samples was wiped off prior to weighing. Immersion testing was carried out at  $23 \pm 2^\circ\text{C}$ .

### **2.4 Dynamic Mechanical Thermal Analysis (DMTA)**

All DMTA was carried out on a DuPont Instruments Model 983 Dynamic Mechanical Analyzer with a liquid nitrogen cooling accessory. The analysis was done in the resonance mode using a temperature ramp of  $5^\circ\text{C}/\text{min}$  from  $-100^\circ\text{C}$  to  $50^\circ\text{C}$ . A typical test sample was 45 mm long X 10 mm wide. The glass transition temperature ( $T_g$ ) of the samples was taken as the maximum in the plot of loss modulus ( $E''$ ) versus temperature.

### **2.5 Gas Chromatography/Mass Spectrometry (GC/MS)**

GC/MS analysis was carried out on a Fisons Platform II quadrupole GC/MS with a Fisons Model 8000 GC. Mass spectra were acquired in the full scan mode (25 atomic mass units (amu) to 500 amu). GC separations were carried out on a 30 m long X 0.25 mm inside diameter 5% phenyl 95% dimethylpolysiloxane ARX-5 capillary column with a  $0.25\mu\text{m}$  thick stationary phase. Helium (flow rate  $1.5\text{mL}/\text{min}$  at  $40^\circ\text{C}$ ) was used as the carrier gas.

The GC oven was programmed to hold at  $40^\circ\text{C}$  for 5 minutes, ramped at a rate of  $10^\circ\text{C}/\text{min}$  to  $300^\circ\text{C}$ , and then held at  $300^\circ\text{C}$  for 9 minutes.

## **3.0 Results and Discussion**

### **3.1 Immersion Testing**

Plots of per cent weight change versus the square root of immersion time ( $t^{1/2}$ ) for the epichlorohydrin (Hydrin 45) and three fluorocarbon elastomers (Materials #2 through #4) in Bayol 35, Voltesso 72, and Marcol 72 are shown in Figures 1 through 4 respectively.

The weight gain of Hydrin 45 varied depending on the immersion fluid. It gained approximately 0.5% in Bayol 35, 2.0% in Voltesso and 3.0% in Marcol 72 after 185 days

of immersion. This variation can be attributed to the difference constituents of the three fill fluids. Marcol 72 is a mixture of saturated cyclic hydrocarbons while Bayol 35 contains saturated straight chain hydrocarbons and Voltesso 35 a mixture of saturated and unsaturated straight chain and cyclic hydrocarbons. These differences effect the absorption of the fluids into the elastomers<sup>5,6,7</sup>. The results indicate that this epichlorohydrin rubber has less resistance to the cyclic hydrocarbons contained in Marcol 72 than to the straight chain hydrocarbons that constitute Bayol 35. The chemical resistance of the rubber to the saturated and unsaturated straight and cyclic hydrocarbons in Voltesso 35 is between that for the other fluids.

Maximum weight gain for the three fluorocarbon elastomers was less than 0.12% by weight (Material #2 in Voltesso 35), while the elastomers lost weight following immersion in some of the fluids. For instance, Material #2 lost weight in Marcol 72, Material #3 loss weight in Bayol 35, Voltesso 35, and Marcol 72, and Material #4 lost a very small amount of weight in Bayol 35. The small weight changes suggest that the fluorocarbon rubber samples have excellent chemical resistance to the constituents of the three hydrocarbon-based fill fluids.

By comparison, 5109S rubber showed much higher per cent weight gain in the hydrocarbon fill fluids. A plot of per cent weight gain versus  $t^{1/2}$  for 5109S neoprene rubber in the same fluids is shown in Figure 5. This rubber had a 6.5% weight gain in Bayol 35, 20.6% weight in Voltesso 35, and a 19.8% weight gain in Marcol 72.

### **3.2 Dynamic Mechanical Analysis**

Plots of  $E''$  against  $T$  for Hydrin 45 before and after immersion in Bayol 35, Voltesso 35 and Marcol 72 for 185 days are shown in Figure 6. The  $T_g$  and per cent weight gain of the elastomer following immersion in the fill fluids is listed in Table 3.

The effect of the absorbed fill fluids was to decrease the glass transition temperature, that is, the temperature of the maximum in the plot of  $E''$  versus temperature, of the elastomer. The decrease was greater for the samples immersed in Voltesso 35 and Marcol 72 than for the sample immersed in Bayol 35. Although Hydrin 45 absorbed less Voltesso 35, than Marcol 72, the Hydrin 45 sample immersed in Voltesso had the lowest  $T_g$ . The decrease in  $T_g$  is consistent with plasticization of the elastomer by the absorbed fill fluids.

Figures 7 through 9 shown plots of  $E''$  versus temperature for fluorocarbon elastomers #2, #3, and #4 prior to and after immersion in Bayol 35, Voltesso 35 and Marcol 72 for 69 days. The  $T_g$ s before and after immersion and per cent weight gains of the elastomers following immersion in the fill fluids are listed in Table 3.

**Table 3**

Per cent weight gain and  $T_g$  of Hydrin 45 and fluorocarbon elastomers #2, #3, and #4 following immersion in Bayol 35, Voltesso 35, and Marcol 72. Immersion time was 185 days for the Hydrin 45 and 69 days for the fluorocarbon elastomers.

Fluid/Material	Hydrin 45		Material #2		Material #3		Material#4	
	% wt gain	$T_g$ (C°)	% wt gain	$T_g$ (C°)	% wt gain	$T_g$ (C°)	% wt gain	$T_g$ (C°)
None	0.0	-16.2	0.0	-16.2	0.0	-16.2	0.0	-8.0
Bayol 35	0.58	-18.9	0.008	-18.1	-0.079	-15.2	-0.035	-8.3
Voltesso 35	1.99	-21.2	0.072	-18.0	-0.089	-18.1	-0.033	-5.5
Marcol 72	3.25	-20.0	-0.117	-18.7	-0.047	-16.1	-0.016	-7.0

The  $T_g$  of Material #2 decreased slightly following immersion in Bayol 35, Voltesso 35 and Marcol 72. The largest change was observed for the sample immersed in Marcol 72. The reduction in  $T_g$  is consistent with absorption of the fill fluids. The fact that Material #2 lost weight in Marcol 72 suggests that something was leached from the elastomer while it was absorbing the fill fluid. It can be seen in Figure 2 that Material #2 lost a

small amount of weight immediately following immersion in the fill fluids. This might be due to the loss of a mold release agent from the surface of the elastomer. However with increasing immersion time Material #2 gained weight in Bayol 35 and Voltesso 35, which is indicative of fluid absorption, but continued to lose weight in Marcol 72.

The  $T_g$  of Material #3 increased slightly following immersion in Bayol 35, decreased slightly following immersion in Voltesso 35, and remained unchanged following immersion in Marcol 72. Comparison of weight changes and changes in  $T_g$  for this elastomer are ambiguous. If the weight loss following immersion in Bayol 35 is due to the loss of a low molecular compound that acted as a plasticizer, an increase in the  $T_g$  of the elastomer would be expected. Although the samples immersed in Voltesso 35 and Marcol 72 also lost weight, the  $T_g$  of the former increased while the  $T_g$  of the latter decreased.

The  $T_g$  of Material #4 varies slightly following immersion in the fill fluids. It decreased slightly following immersion in Bayol 35, increased following immersion in Voltesso, and increased slightly following immersion in Marcol 72. This elastomer lost a very small amount of weight in all three fluids.

### 3.3 GC/MS Analysis of Fill Fluids

To determine if the fill fluids were leaching something from the epichlorohydrin and fluorocarbon elastomers, samples of the fill fluid before and after elastomer immersion were analyzed by gas chromatography/mass spectrometry. Chromatograms of Bayol 35, and Bayol 35 samples after exposure to Hydrin 45, and fluorocarbon elastomers #2, #3, and #4 are shown in Figure 10. Figure 11 shows an expansion of the chromatograms between 20.00 and 40.00 minutes. There are phthalic acid esters in the chromatograms of the fill fluid before and after immersion of elastomers, for instance, benzyl butyl phthalate (27.19 minutes) and dioctyl phthalate (28.67 minutes). These compounds are

commonly used plasticizers. Their presence in the fill fluid prior to the rubbers being immersed indicates that they did not come from the elastomers.

GC/MS analyses of Voltesso 35 and Marcol 72 after exposure to the four elastomers were similar to Bayol 35. That is, the analysis did not indicate that any compounds were being leached from the elastomers into these fluids.

#### **4.0 Conclusions**

The Hydrin 45 rubber has excellent resistance to Bayol 35 absorbing less than 0.6% by weight Bayol 35 after 185 days immersion. This was confirmed by DMA, that is, the  $T_g$  decreased by less than 3 degrees. Hydrin 45 also exhibited good resistance to Voltesso 35 and Marcol 72, although it absorbed 2.0% by weight and 3.25% by weight of these fluids respectively.

The three fluorocarbon elastomers, Materials #2, #3, and #4, have excellent chemical resistance to Bayol 35, Voltesso 35, and Marcol 72. The weight change of these elastomers after immersion is very small and the  $T_g$  of the elastomers changes very little following immersion.

In Reference 1 it was noted that fluorocarbon elastomer QXA 3770 became glassy at 0°C and approximately 500Hz. The  $T_g$  of fluorocarbon elastomer #4 is higher than QXA3770 and will become glassy at frequencies below 500Hz. The  $T_g$  of Hydrin 45 and fluorocarbon elastomers #2 and #3 are lower than fluorocarbon elastomer #4, however, if service conditions include temperatures at 0°C or lower and frequencies above 500 Hz these elastomers will also be in the glassy state.

It is recommended that epichlorohydrin-based elastomers which have lower  $T_g$ s than Hydrin 45 be evaluated for use as boot materials. Epichlorohydrin-based copolymers and terpolymers are available and have lower  $T_g$  than the homopolymer. However, the



chemical resistance of the copolymer and terpolymer rubbers will be different than the homopolymer rubber and should be evaluated.

### **5.0 References**

1. John A. Hiltz and Irvin A. Keough, "The Effect of Hydrocarbon Fill Fluids on 5109S Neoprene and QXA 3770 Fluorocarbon Rubbers", DREA Technical Memorandum TM/98/203, January 1998.
2. Canadian Centre for Occupational Health and Safety, MSDS Number 248150, Bayol 35, Prepared September 27, 1994.
3. Canadian Centre for Occupational Health and Safety, MSDS Number 243020, Voltesso 35, Prepared October 10, 1995.
4. Canadian Centre for Occupational Health and Safety, MSDS Number 248619, Marcol 72, Prepared September 15, 1994.
5. John A. Hiltz, Richard M. Morchat and Irvin A. Keough, "A DMTA Study of the Fuel Resistance of Elastomers", *Thermochimica Acta*, 226 (1993) 143-154.
6. S. B. Harogopad and T. M. Aminabhavi, *Polymer Communications*, 32 (1991) 120.
7. S. B. Harogopad and T. M. Aminabhavi, *Polymer*, 32 (1991) 870.

### Hydrin 45

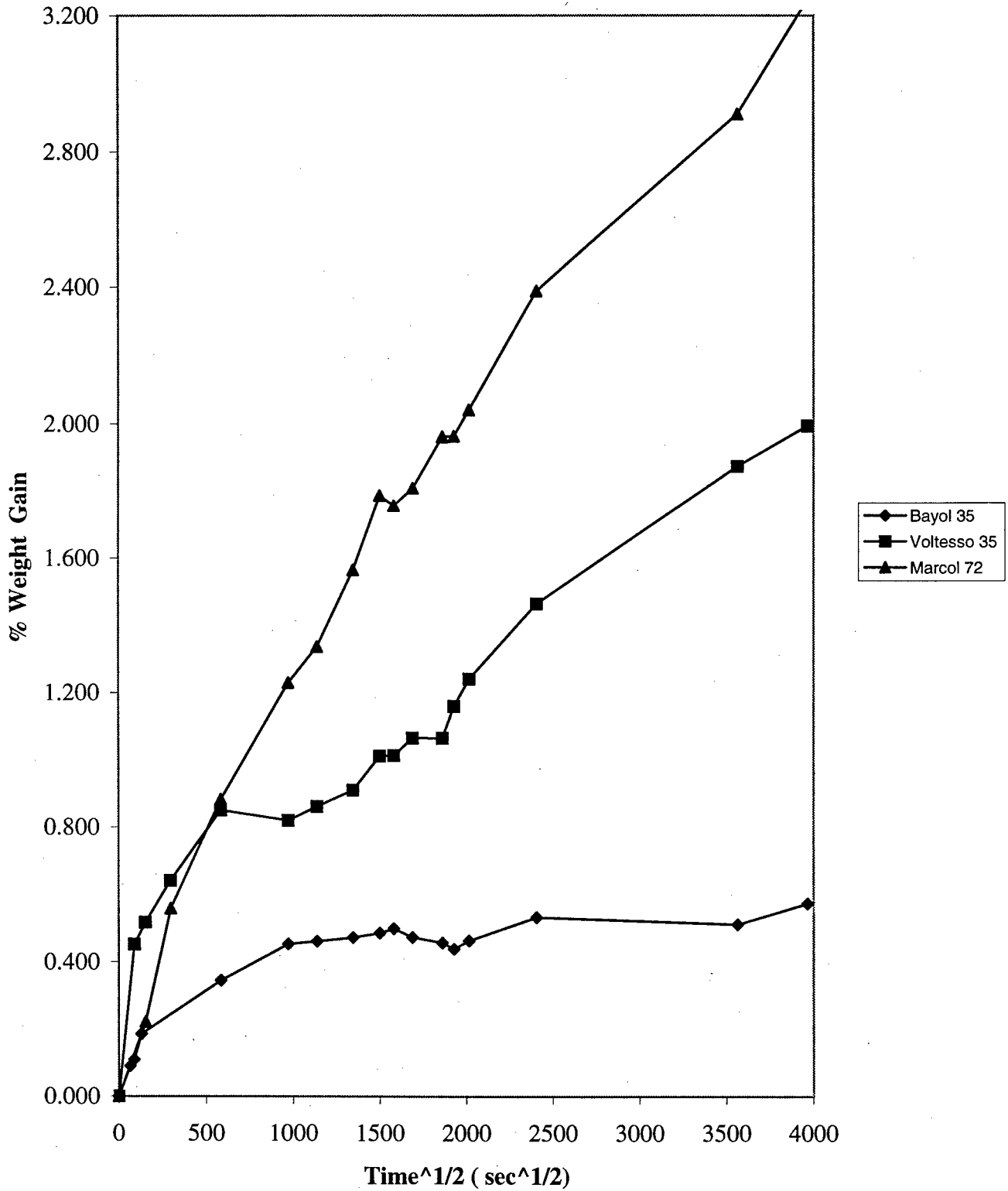


Figure 1 – Plots of percentage weight gain of samples of Hydrin 45 rubber against immersion time<sup>1/2</sup> in Bayol 35, Voltesso 35, and Marcol 72.

## Fluorocarbon Elastomer #2

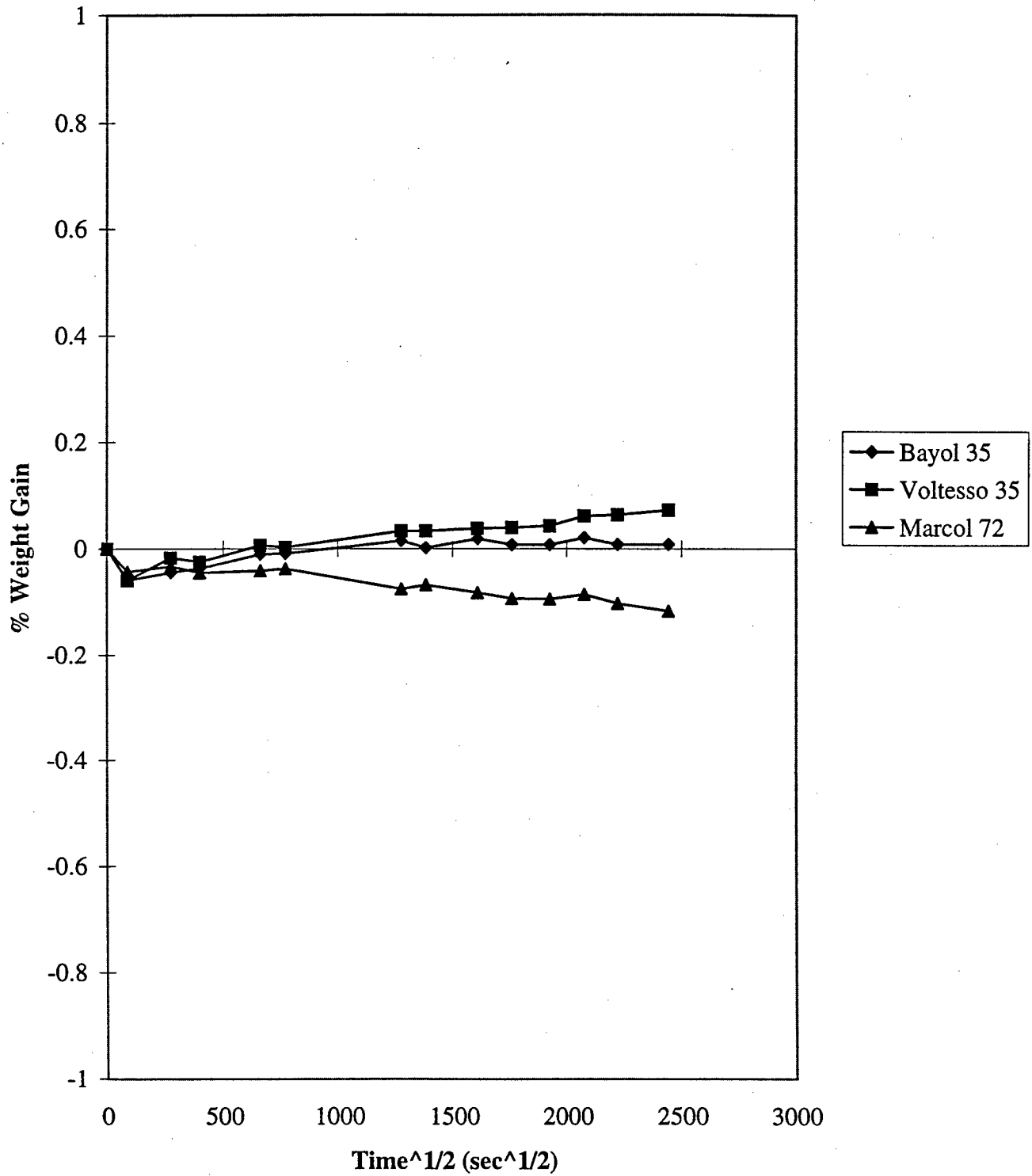


Figure 2 – Plots of percentage weight gain of samples of fluorocarbon elastomer #2 against immersion time<sup>1/2</sup> in Bayol 35, Voltesso 35, and Marcol 72.

### Fluorocarbon Elastomer #3

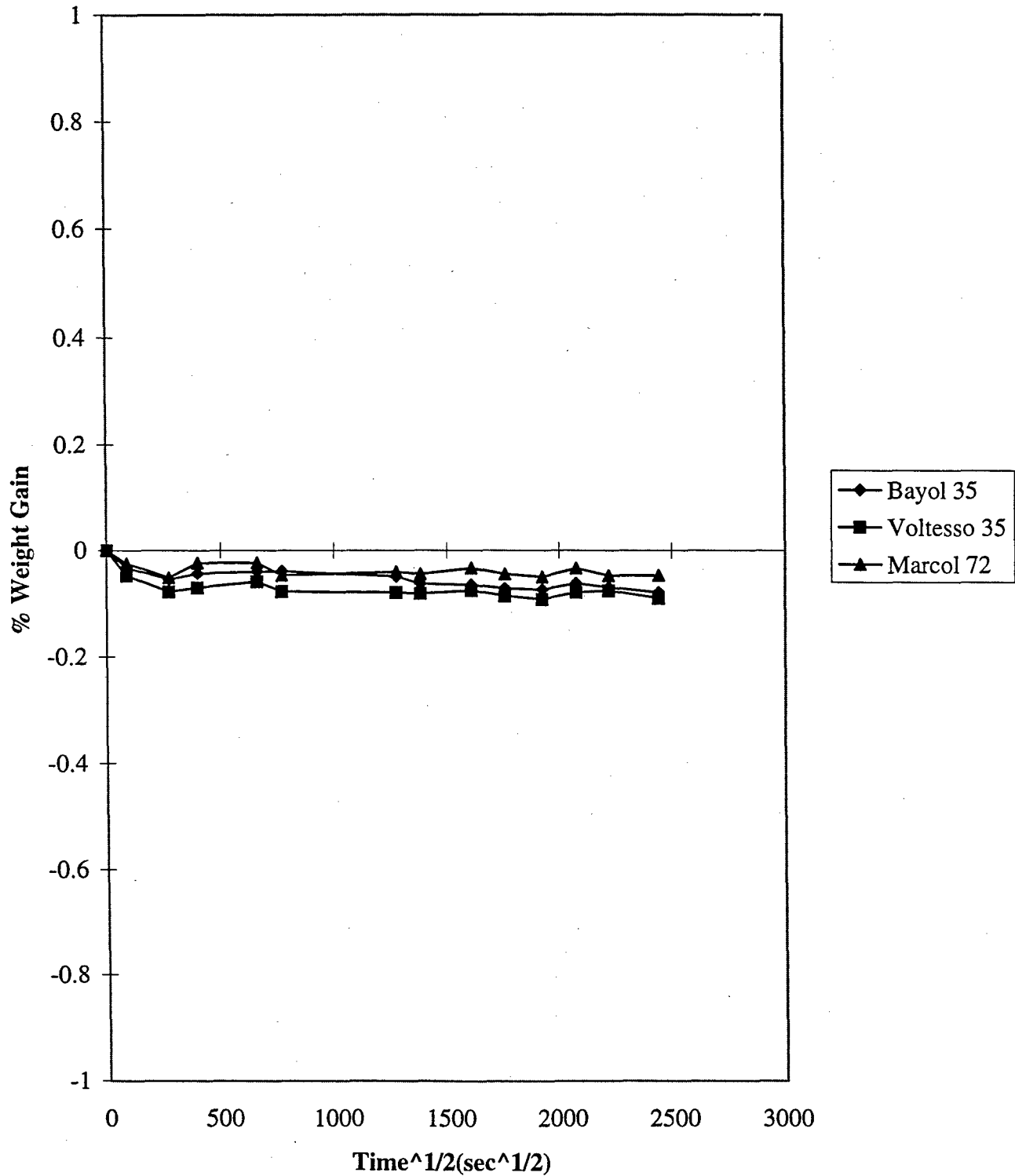


Figure 3 – Plots of percentage weight gain of samples of fluorocarbon elastomer #3 against immersion time<sup>1/2</sup> in Bayol 35, Voltesso 35, and Marcol 72.

## Fluorocarbon Elastomer #4

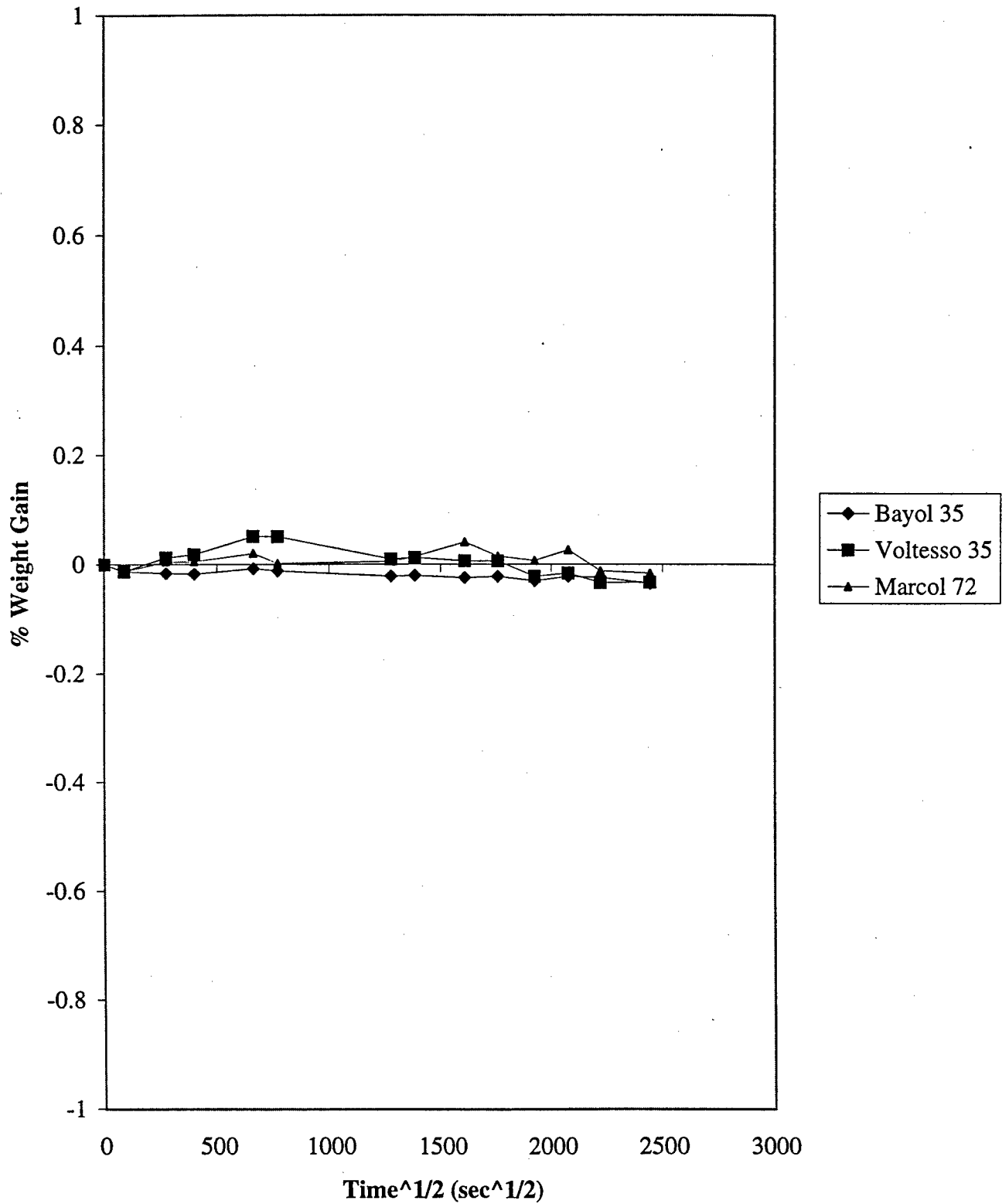


Figure 4 – Plots of percentage weight gain of samples of fluorocarbon elastomer #4 against immersion time<sup>1/2</sup> in Bayol 35, Voltesso 35, and Marcol 72.

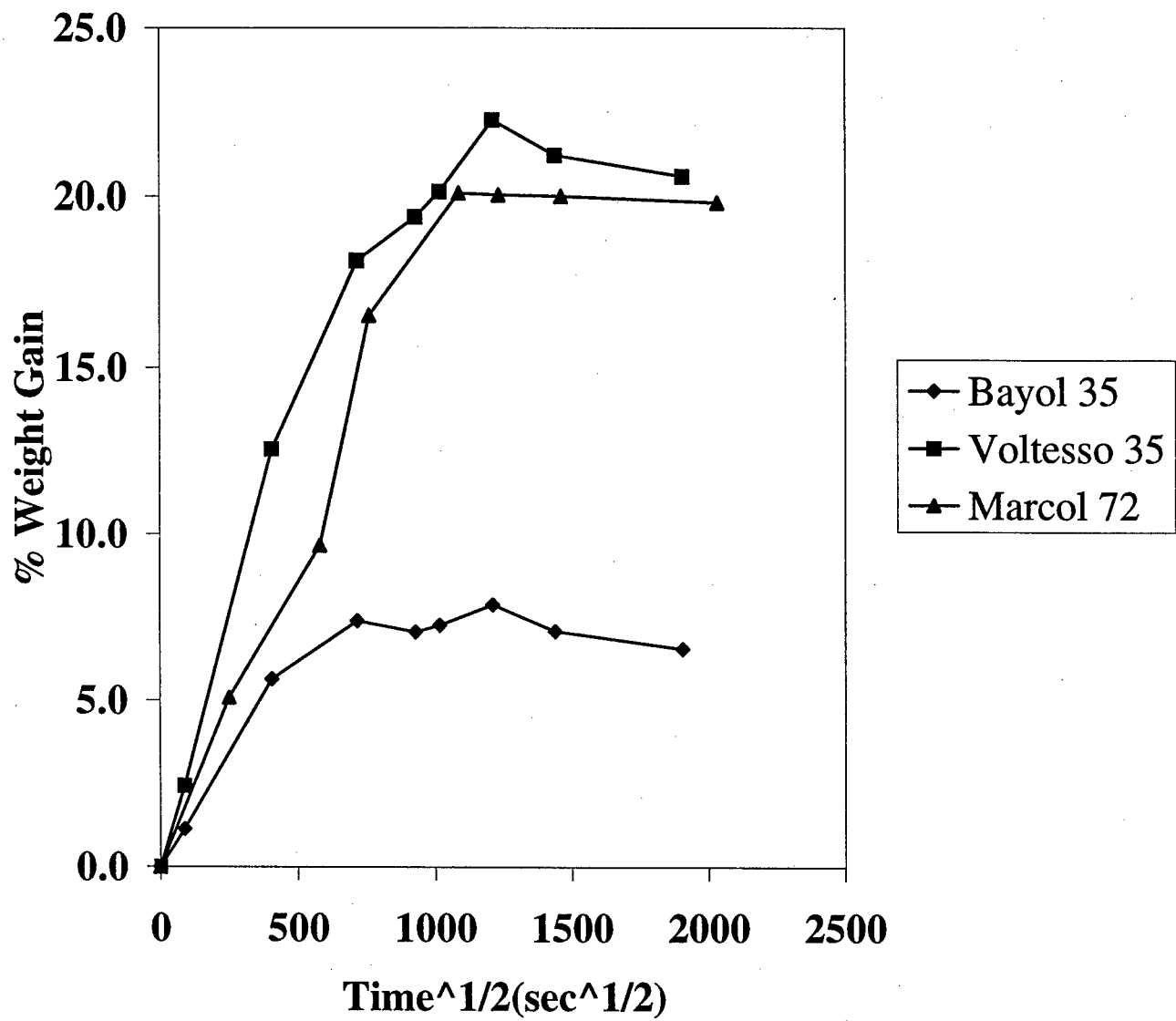


Figure 5 – Plots of percentage weight gain of 5109S rubber samples against immersion time<sup>1/2</sup> in Bayol 35, Voltesso 35, and Marcol 72.

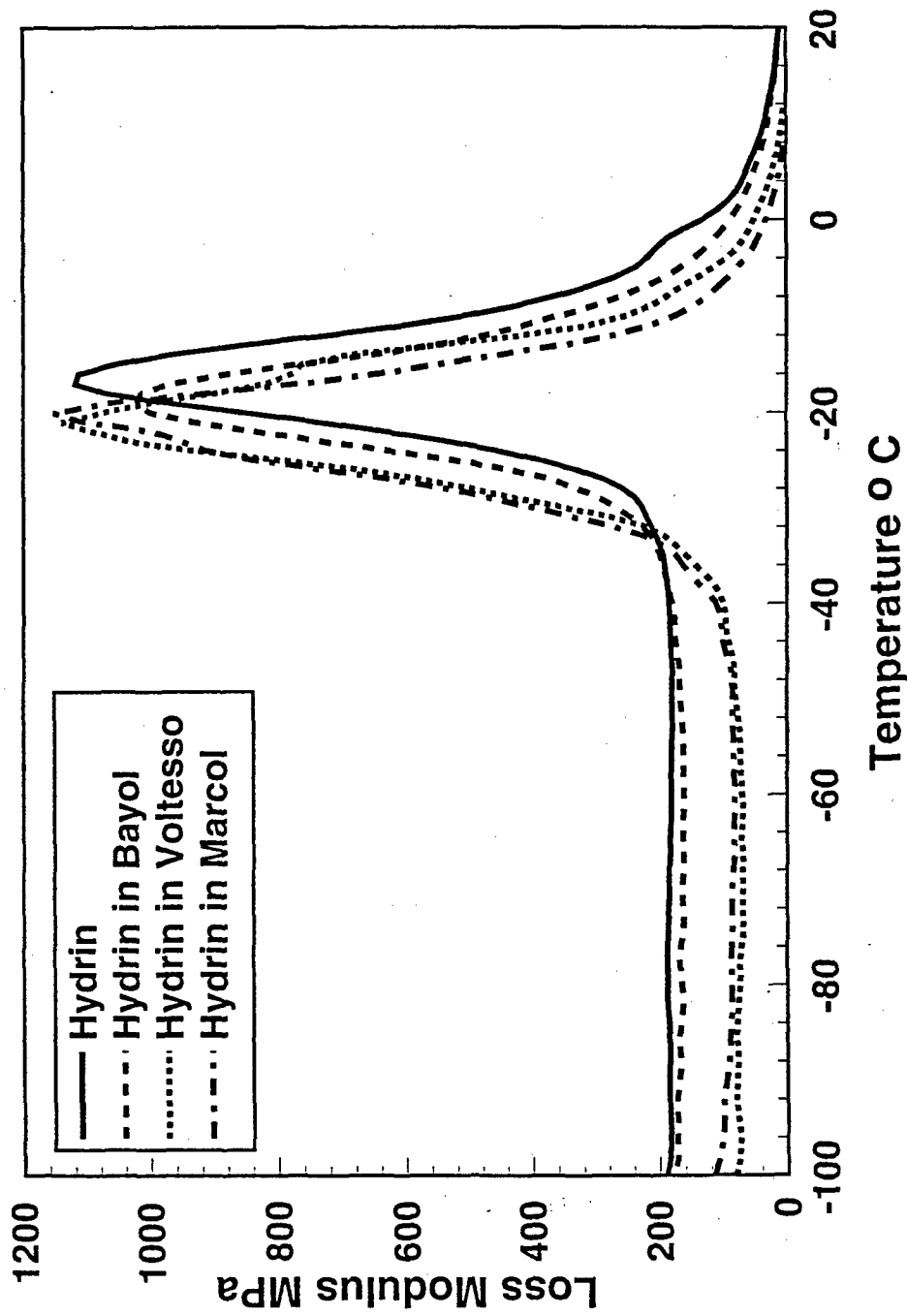


Figure 6 - Plot of E'' versus temperature for Hydrin 45 rubber before and after exposure to Bayol 35, Voltesso 35, and Marcol 72.

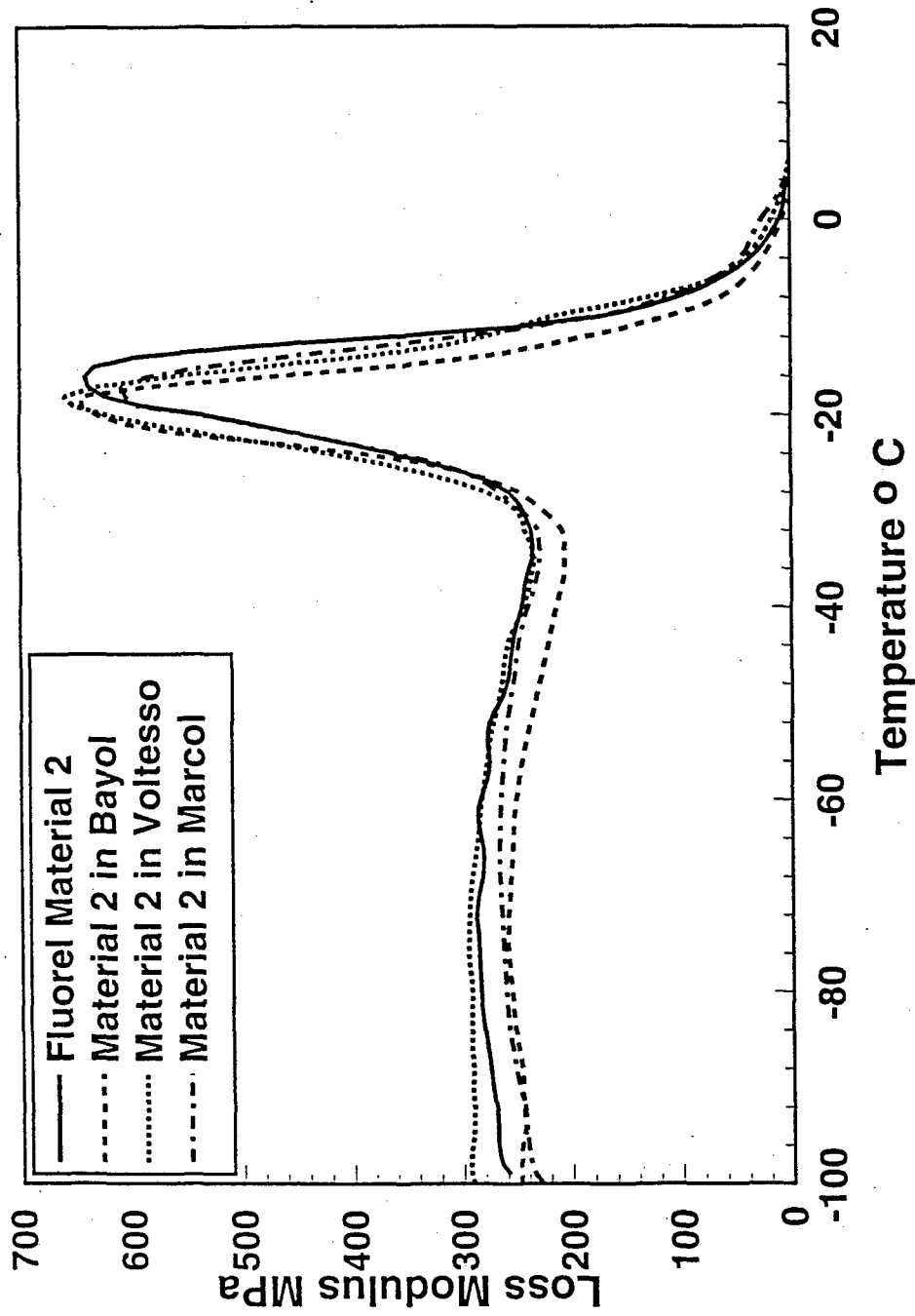


Figure 7 – Plot of E'' versus temperature for fluorocarbon elastomer Material #2 before and after exposure to Bayol 35, Voltesso 35, and Marcol 72.



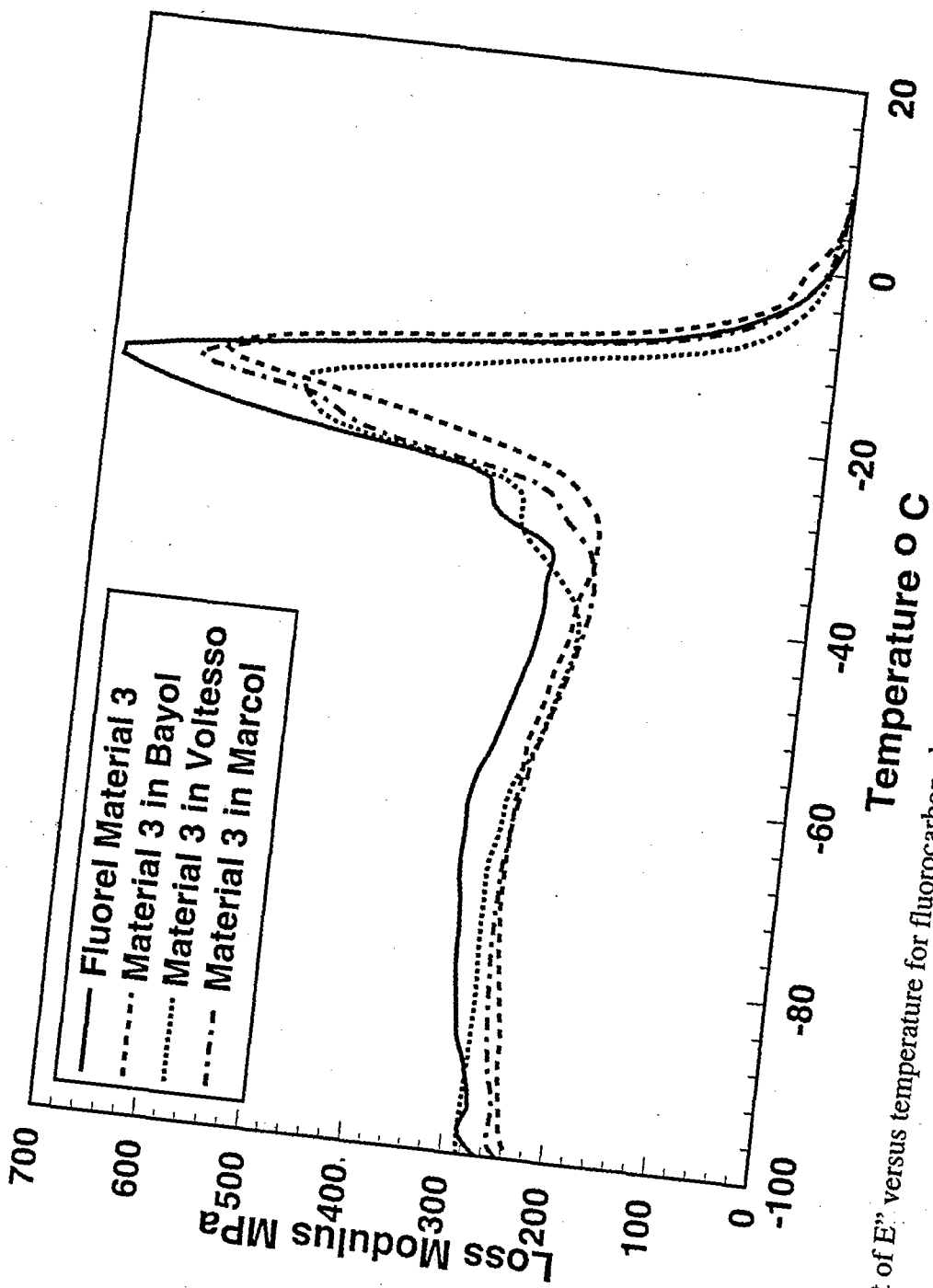


Figure 8 - Plot of  $E''$  versus temperature for fluorocarbon elastomer Material #3 before and after exposure to Bayol 35, Voltesso 35, and Marcol 72.

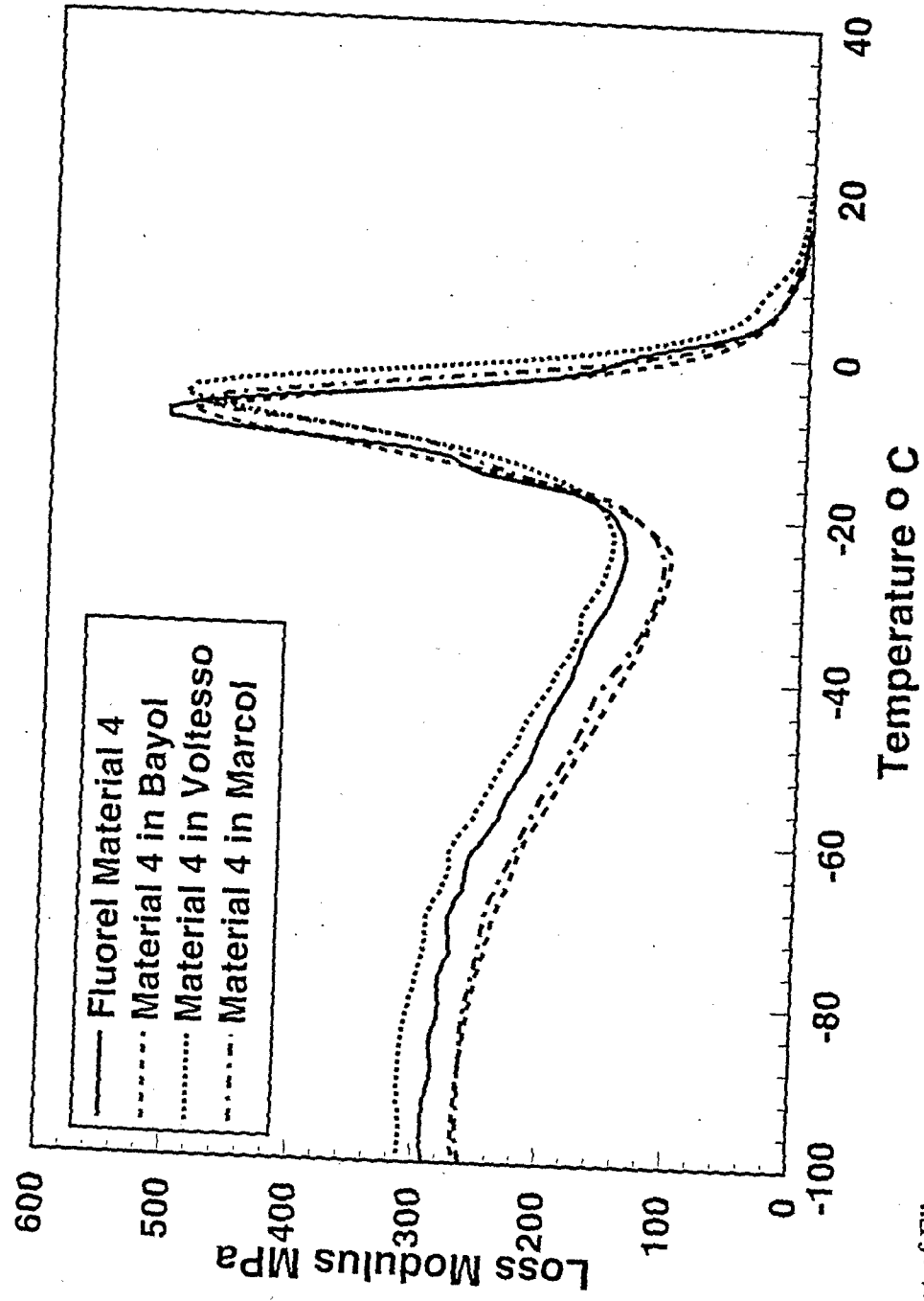


Figure 9 – Plot of  $E''$  versus temperature for fluorocarbon elastomer Material #4 before and after exposure to Bayol 35, Vofresso 35, and Marcol 72.

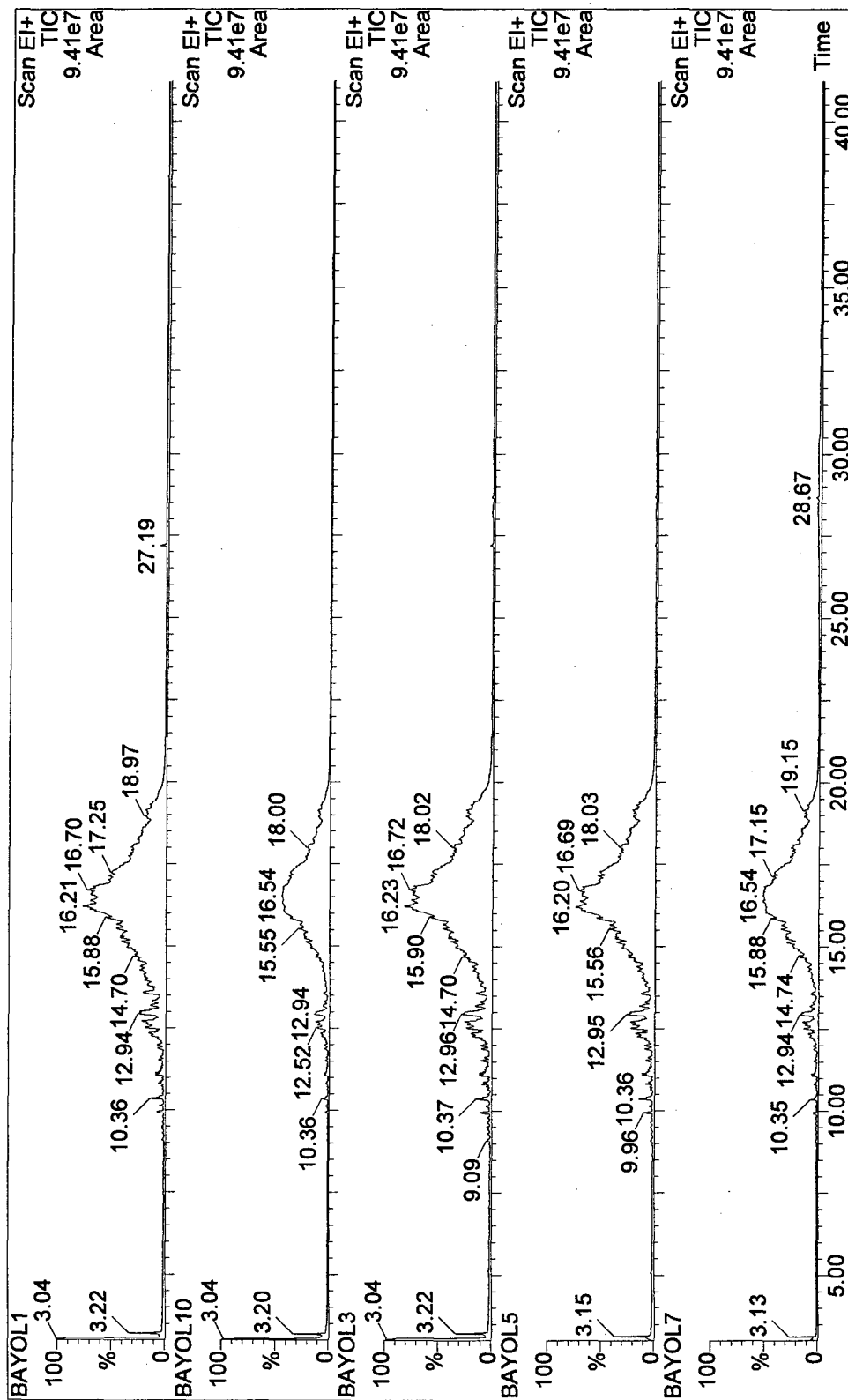


Figure 10 – From top to bottom, chromatograms of Bayol 35, and Bayol 35 samples after exposure to Hydrin 45, and fluorocarbon elastomers #2, #3, and #4.

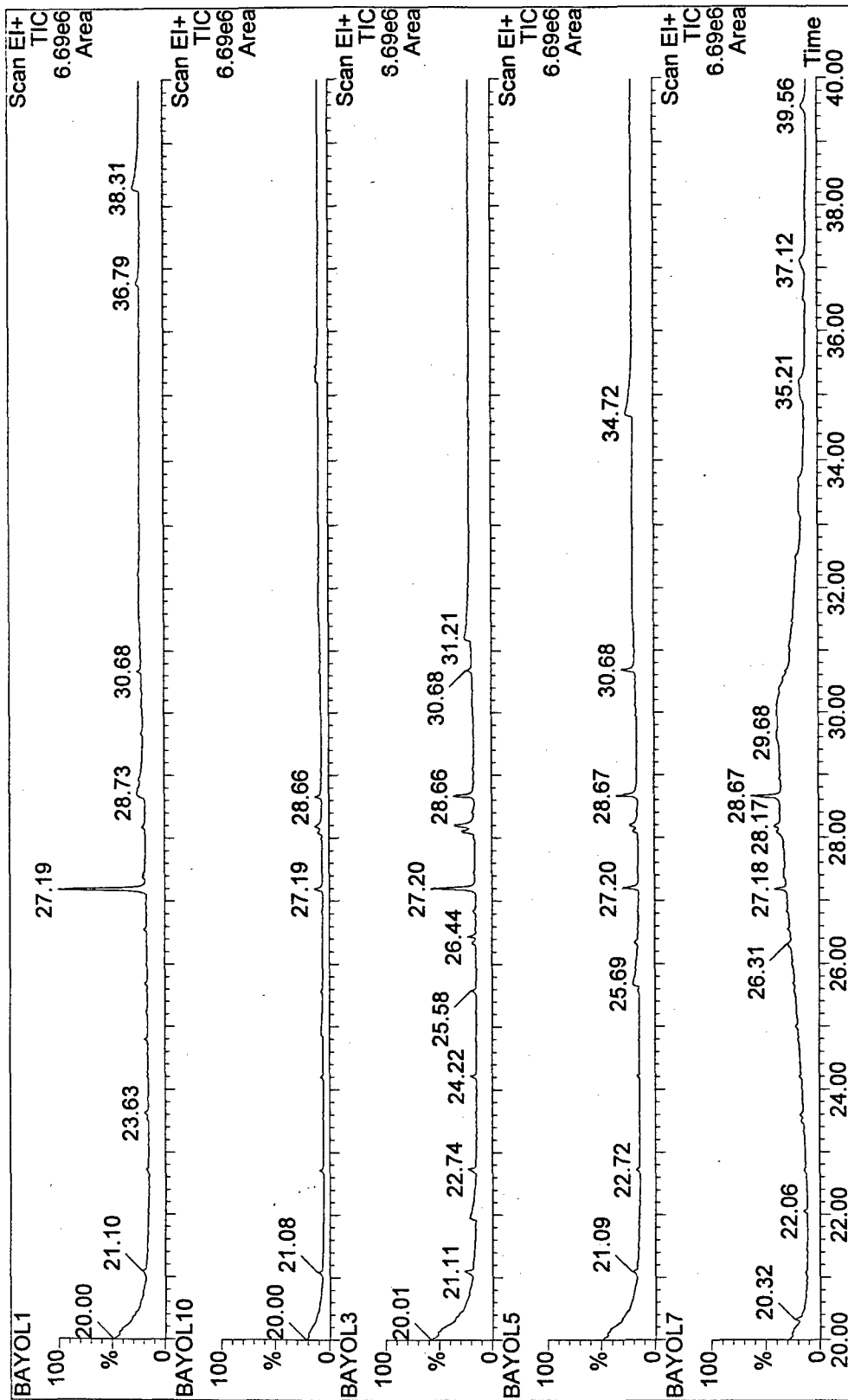


Figure 11 – From top to bottom, expansions of chromatograms of Bayol 35, and Bayol 35 samples after exposure to Hydrin 45, and fluorocarbon elastomers #2, #3, and #4 between 20.00 and 40.00 minutes.

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The chemical resistance of an epichlorohydrin elastomer and three fluorocarbon elastomers to Bayol 35, Voltesso 35, and Marcol 72 hydrocarbon fill fluids has been investigated. Absorption of fill fluid and the resulting change in the glass transition temperature were used to evaluate the chemical resistance of the elastomers. The weight change of the fluorocarbon elastomers was less than 0.1% by weight indicating that these elastomers have excellent chemical resistance to the fluids. The epichlorohydrin elastomer absorbed approximately 0.6% Bayol 35, 2.0% Voltesso 35, and 3.25% Marcol 72 and the  $T_g$  of the epichlorohydrin elastomer decreased slightly following immersion in the fill fluids. This elastomer has good to excellent resistance to the fill fluids. The  $T_g$  of the four elastomers studied here are high enough to cause concern about these elastomers undergoing a rubber to glass transition in low temperature, high frequency applications. Epichlorohydrin based copolymer or terpolymer elastomers have lower  $T_g$ s and should remain rubbery at low temperature and higher frequencies. Evaluation of these elastomers is warranted.

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