

**AFRL-PR-WP-TP-2006-235**

**A COMPARISON OF THE AC  
BREAKDOWN STRENGTH OF NEW  
AND USED POLY A-OLEFIN OIL TO  
TRANSFORMER OIL (Preprint)**



**C. Yeckel, R.D. Curry, and P. Norgard**

**APRIL 2006**

**Approved for public release; distribution is unlimited.**

**STINFO COPY**

**This work, resulting in whole or in part from Department of the Air Force contract number F33615-01-C-2191, has been submitted to IEEE for publication in the Proceedings of the 27th IEEE International Power Modulator Conference 2006. If this work is published, IEEE may assert copyright. The United States has for itself and others acting on its behalf an unlimited, paid-up, nonexclusive, irrevocable worldwide license to use, modify, reproduce, release, perform, display, or disclose the work by or on behalf of the Government. All other rights are reserved by the copyright owner.**

**PROPULSION DIRECTORATE  
AIR FORCE RESEARCH LABORATORY  
AIR FORCE MATERIEL COMMAND  
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7251**

<b>REPORT DOCUMENTATION PAGE</b>				<i>Form Approved</i> OMB No. 0704-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. <b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b></p>					
<b>1. REPORT DATE (DD-MM-YY)</b> April 2006		<b>2. REPORT TYPE</b> Conference paper preprint		<b>3. DATES COVERED (From - To)</b> 04/21/2006 – 04/21/2006	
<b>4. TITLE AND SUBTITLE</b> A COMPARISON OF THE AC BREAKDOWN STRENGTH OF NEW AND USED POLY A-OLEFIN OIL TO TRANSFORMER OIL (Preprint)				<b>5a. CONTRACT NUMBER</b> F33615-01-C-2191	
				<b>5b. GRANT NUMBER</b>	
				<b>5c. PROGRAM ELEMENT NUMBER</b> 62203F	
<b>6. AUTHOR(S)</b> C. Yeckel, R.D. Curry, and P. Norgard (University of Missouri-Columbia)				<b>5d. PROJECT NUMBER</b> 3145	
				<b>5e. TASK NUMBER</b> 29	
				<b>5f. WORK UNIT NUMBER</b> 314529M0	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  University of Missouri-Columbia Office of Sponsored Programs 310 Jesse Hall Columbia, MO 65211				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  Propulsion Directorate Air Force Research Laboratory Air Force Materiel Command Wright-Patterson AFB, OH 45433-7251				<b>10. SPONSORING/MONITORING AGENCY ACRONYM(S)</b> AFRL-PR-WP	
				<b>11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)</b> AFRL-PR-WP-TP-2006-235	
<b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited.					
<b>13. SUPPLEMENTARY NOTES</b> To be presented at the 27th IEEE International Power Modulator Conference 2006. This work, resulting in whole or in part from Department of the Air Force contract number F33615-01-C-2191, has been submitted to IEEE for publication in the Proceedings of the 27th IEEE International Power Modulator Conference 2006. If this work is published, IEEE may assert copyright. The United States has for itself and others acting on its behalf an unlimited, paid-up, nonexclusive, irrevocable worldwide license to use, modify, reproduce, release, perform, display, or disclose the work by or on behalf of the Government. All other rights are reserved by the copyright owner. Best quality available.					
<b>14. ABSTRACT</b>  The breakdown performance of an advanced synthetic dielectric coolant, poly-alpha olefin, is compared to conventional transformer oil over a range of temperatures from 10 to 50 °C. The poly-olefin oil is first benchmarked against conventional transformer oil, and then compared to poly-olefin oil that has been exposed to a large number of high-energy discharges in order to establish the effects of oil age on performance. The results obtained from the standard ANSI D877 testing procedure are then compared to the results of a modified test procedure.					
<b>15. SUBJECT TERMS</b>					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT:</b> SAR	<b>18. NUMBER OF PAGES</b> 10	<b>19a. NAME OF RESPONSIBLE PERSON (Monitor)</b> Susan Heidger <b>19b. TELEPHONE NUMBER (Include Area Code)</b> (937) 255-6235
<b>a. REPORT</b> Unclassified	<b>b. ABSTRACT</b> Unclassified	<b>c. THIS PAGE</b> Unclassified			

# A COMPARISON OF THE AC BREAKDOWN STRENGTH OF NEW AND USED POLY- $\alpha$ OLEFIN OIL TO TRANSFORMER OIL

C. Yeckel, R. D. Curry, and P. Norgard

University of Missouri – Columbia  
Department of Computer and Electrical Engineering

## Abstract

The breakdown performance of an advanced synthetic dielectric coolant, poly- $\alpha$  olefin, is compared to conventional transformer oil over a range of temperatures from 10 to 50 °C. The poly- $\alpha$  olefin oil is first benchmarked against conventional transformer oil, and then compared to poly- $\alpha$  olefin oil that has been exposed to a large number of high-energy discharges in order to establish the effects of oil age on performance. The results obtained from the standard ANSI D877 testing procedure are then compared to the results of a modified test procedure.

## I. INTRODUCTION

The high-pressure switch program at the University of Missouri – Columbia is presently utilizing synthetic dielectric oil as the switching medium [1]. The oil is poly- $\alpha$  olefin, or PAO, and is relatively unknown to the Pulsed Power industry. The PAO is a highly branched, compact, and very stable synthetic hydrocarbon that is recommended for use as a dielectric cooling fluid for aircraft avionics systems, high-powered transmitter equipment, power supplies, and ordinance systems. The temperature of the PAO utilized in the high-pressure switch program routinely experiences thermal fluctuations while tests are being performed. The effects of the thermal fluctuations of PAO on the breakdown performance are currently not known within the literature. This paper reports on tests performed to address the question of how temperature impacts breakdown performance of PAO, how that performance compares to conventional transformer oil, and how a slight modification in oil conditioning may improve breakdown results.

Liquid dielectric breakdown is related to fluid viscosity, which is in turn related to the fluid temperature for most useful dielectric liquids. Viscosity is the property of a fluid that allows momentum in one plane to be transferred to a different plane [2]. In the case of the two dielectric oils under study, transformer oil and PAO, the viscosity of the oil increases as the temperature of the oil decreases. Figure 1 summarizes the change in viscosity for both oils over a large range of temperatures[3,4]. Both oils have a knee at which the viscosity dependence on temperature saturates.

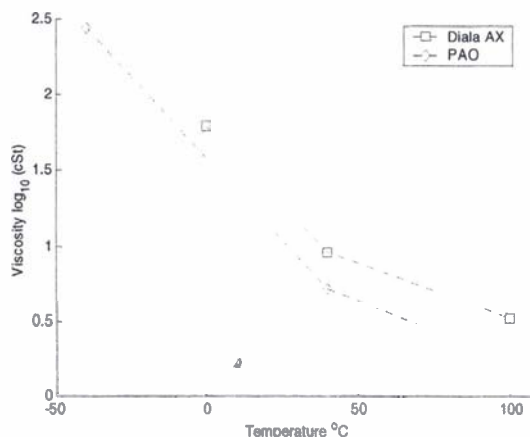


Figure 1. Temperature versus viscosity for oils tested

Liquid breakdown under the application of a long duration voltage pulse is believed to be the result of the formation of, and subsequent breakdown of a gaseous bubble [5]. Forces generated under the application of an electric field act along the lines of the electric field, according to the Lorentz force equation. In a highly viscous fluid the motion that results from the Lorentz force can be transmitted perpendicularly, resulting in the establishment of a low density region along the lines of constant electric field. In highly viscous fluids the ability of the fluid to flow into this region of low density is impeded and under the right conditions a bubble can form [6]. Fluid viscosity, when it is large, is therefore seen as an important parameter in defining breakdown.

## II. OIL TEST PROCEDURE

### A. Test Stand

All testing was performed with the OC60D-A Hubbell Hipotronics High Voltage Tester shown in figure 2. The tester is capable of applying a 3kV/s voltage rise across an electrode gap at 60Hz AC. The cathode and anode are 1 in. diameter flat electrodes with 0.1 in. gap spacing. All voltages reported by the tester are RMS values.

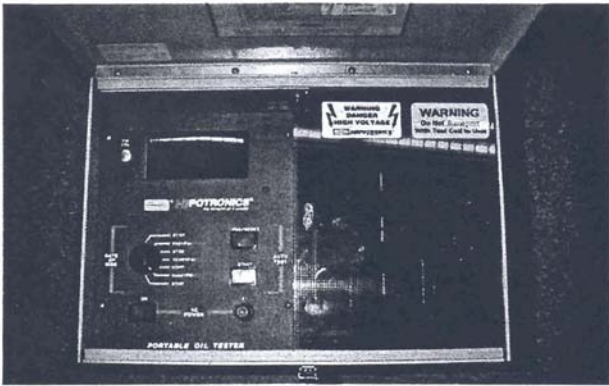


Figure 2. This picture is a top-view of H.V. Tester.

### B. Oil Breakdown Tests

Data was generated by utilizing two oil conditioning methods. The second oil conditioning method deviates slightly from the first method and was implemented to allow for comparison between two oil conditioning procedures.

#### 1) First Test Method

Oils marked for the first test method were filtered through a 1 um filter and degassed in a vacuum chamber at 40°C. The oil was then equilibrated at temperatures of 20, 25, 30, 35, and 40°C in an oven. Two tests of five shots each were then performed on each oil sample at each temperature for a total of 150 shots. The sample was replaced after every five shots.

#### 2) Second Test Method

Oils marked for the second test method were filtered through a 0.45 um filter. The sample was then rigorously bubbled with dry nitrogen for 10 minutes before being degassed in a vacuum chamber at 40°C. Each oil sample was then equilibrated at temperatures of 10, 20, 30, 40, and 50°C in an oven. One test of five shots each was then performed on each oil at each temperature for a total of 75 shots. The oil sample was replaced after every shot.

## II. RESULTS AND ANALYSIS

Data obtained from these testing procedures is presented in figures 3, 4, 5, and 6. Figures 3, 4, and 5 present data from the first test method while figure 6 presents data from the second test method.

### A. Data Presentation

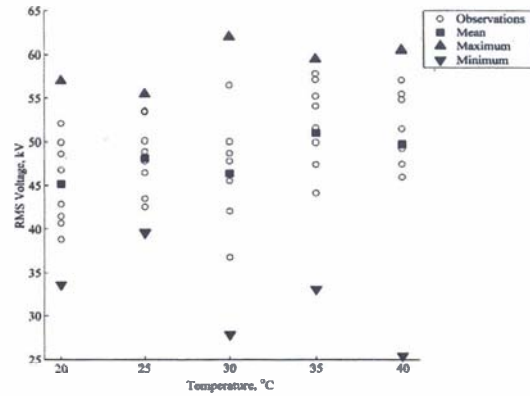


Figure 3. Filtered Diala AX, breakdown data – “first test method.”

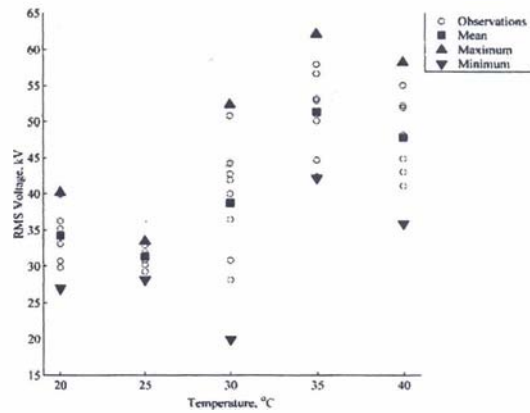


Figure 4. Filtered new PAO, breakdown data – “first test method.”

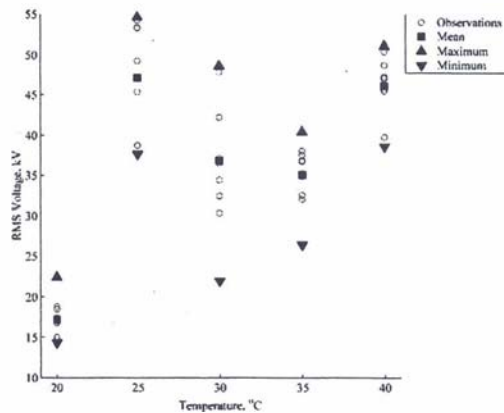


Figure 5. Filtered used PAO, breakdown data – “first test method.”

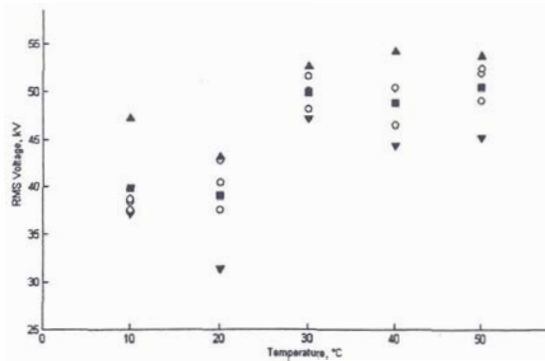


Figure 6. Filtered new PAO breakdown data – “second test method.”

### B. Statistical Analysis

A Student-Newman-Keuls statistical test was performed on the data obtained from the standard test method. An SNK test compares the means obtained from the data and is able to determine interactions between test variables. The test determined the interactions between the variables of three oils sampled.

## IV. DATA DISCUSSION

Several interactions are observed from the data. Observational analysis can be performed by comparing the mean voltage breakdown of each case. The mean breakdown of the Diala AX data deviates significantly less than the mean breakdown of the PAO at all temperatures. The mean breakdown of the PAO is observed to deviate with changing temperature. The SNK test results support this observational analysis. Results from the SNK test show that there is a strong interaction between temperature and oil in the case of the PAO and a weak interaction in the case of the Diala AX.

It can also be observed that the PAO exhibits a smaller range and variance in almost all temperature cases than the Diala AX. That is, the PAO broke down at more consistent values.

The breakdown voltages of the new PAO obtained from the first and second test methods are also compared. Both test methods show the same voltage breakdown trend. However, the new PAO subjected to the second test method displays a much tighter range and variance.

## V. CONCLUSION

From the data discussion it was determined that the mean breakdowns of PAO depends much more on temperature than the mean voltage breakdowns of Diala AX. This interaction may be due to the viscosities of PAO and Diala AX. At room temperatures, Diala AX has twice the viscosity of PAO. The lower viscosity of the PAO may allow bubbles to form with less difficulty, thus forming greater temperature dependence at the

temperatures tested. However, the mechanism of breakdown must be investigated further.

The influence of charge formation on oil viscosity has been analyzed by Dikarev et al. It was determined that the application of electric fields on transformer oil increases the viscosity of that oil. At 30 KV the transformer oil marked a 30% increase in viscosity [7]. The oil temperature has an inverse affect on oil viscosity. This viscosity factor may impact on the physics of bubble formation, charge injection, and electrode erosion. The increase in viscosity may cause unexpected pressure fluctuations in flowing oil systems.

In addition to the first test method, a second test method was also implemented in the case of new PAO. The second test method incorporates dry nitrogen sparging through the oil in an attempt to further condition the oil by eliminating all traces of water. It is apparent from the data that the bubbling of any nitrogen improved the voltage breakdown range and variance when applied to new PAO. Thus water contamination may also play an important part in the large deviation of the voltage breakdown.

The similarity in breakdown trends between the first and second testing method verifies the assumption that there is a strong interaction between temperature and oil in the case of new PAO. To what extent replacing the sample after every shot instead of after every five shots influenced the data, however, is unknown at this time.

## VI. REFERENCES

- [1] R. Curry *et al*, "Development of High Power, High Pressure, Rep-Rate, Liquid Dielectric Switches," Pulsed Power Conference, 2003, Digest of Technical Papers, PPC-2003, 14th IEEE International, Volume: 1, 15-18 June 2003 Pages: 599 – 602
- [2] L. Malvern, Introduction to the Mechanics of a Continuous Medium. Englewood Cliffs, NJ: Prentice-Hall, 1969
- [3] Shell Diala AX Electrical Insulating Oil, *Technical Datasheet*, April, 2005
- [4] Anderol Royco 602: Coolant for Aircraft Avionics Systems, *Technical Datasheet*, October, 2004
- [5] Z. Krasucki, "Breakdown of Liquid Dielectrics," Proceedings of the Royal Society of London, Series A, Mathematical and Physical Sciences, Volume: 294, No. 1438, Oct. 4, 1966 Pages: 393-404
- [6] T.J. Lewis, J.P. Llewellyn, and M.J. van der Sluijs, "Electromechanical Strain at Dielectric Interfaces," Conf. on Elec. Ins. And Dielectric Phenomena, 1992 Annual Report, Oct. 1992, Pages: 345-350
- [7] B.N. Dikarev, A.A. Ostapenko, G.G. Karasev, "Viscosity Dependence of Dielectric Liquids on Electric Field," Conduction and Breakdown in Dielectric Liquids, 1993., ICDL '93., IEEE 11th International Conference on 19-23 July 1993 Page(s): 509 – 513