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On Orbit Daytime Solar Heating Effects: A Comparison of Ground Chamber Arcing Results

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Summary

The purpose of the current experiment is to make direct comparisons between the arcing results obtained from the diffusion pumped vertical chamber and our newly renovated Teney vacuum chamber which is equipped with a cryogenic pump. Recall that the prior reported results obtained for the Vertical chamber were nominal at best, showing only a slight reduction in the arc rate after 5 heating cycles at the lower bias potentials and virtually no changes at high potential biases.[1,2] It was concluded that the vertical chamber was unable to remove enough water vapor from the chamber to adequately test the arcing criterion. Because the cryo-pumped Teney chamber has a ten times better pumping speed, (40,000 liters per sec compared to 4,000 liters per sec for the diffusion pumped vertical chamber), a decision was made to retest that experiment in both the Teney and Vertical vacuum chambers. A comparison of the various data is presented with encouraging results.

Introduction

For the current experiments silicon photovoltaic arrays are placed under simulated daytime solar heating (full sunlight) conditions typically encountered in a Low Earth Orbit (LEO) environment. Assuming a 220 km LEO orbit the array will reach a temperature of about 80 °C in full sunlight. It is our contention that a desorbed molecular ionization mechanism involving water vapor, at the triple junction sites on a solar array, is directly responsible for arcing onset of solar arrays in LEO.[3–9] The solar array arcing criterion is used to validate our hypothesis that the arc rate depends on the water vapor content stored in the array. Because solar heating of the array seeks to drive out absorbed water vapor, a reduction in water vapor should lead to a reduction in the arcing rare. Arc rates are established for individual arrays held at 11 °C and are used as a baseline for further comparisons. As in the previous experiment the arrays were heated to a temperature of 80 °C. Each thermal cycle was set to time duration of 40 minutes to approximate the daytime solar heat flux to the array over a single orbit. The arrays are allowed to cool back down to ambient temperature before proceeding to the next thermal cycle. After 5 complete heating cycles the arc rates of the solar arrays are then retested at a temperature of 11 °C.

Experimental Setup

Figure 1 shows a picture of the 2.2 meter (diameter) by 3.0 meter (length) Vertical Chamber (Left) and the 1.8 meter (diameter) by 2.0 meter (length) of the cryo-pumped Teney vacuum chamber (Right). Figure 2 shows two solar arrays hanging in front of an aluminum plate equipped with resistive heating elements which are used to simulate the solar heat flux to the array. Two type T thermocouples were used to monitor the array and heater plate temperatures. Arrays samples 62 and 63 are each composed of thirty six 4 by 6 centimeter silicon solar cells arranged as 3 parallel strings, each string being composed of 12 cells wired in series. At experiment startup the base neutral background pressure (P_o) in the chamber at 14 °C was recorded at $P_o = 5.7\times10^{-7}$ Torr. A Kaufman plasma source was used to ionize xenon gas neutrals via a hot wire filament for the experiments. In principle xenon gas is carefully metered into the chamber using a user controlled leak valve and an ionization gauge was used to read back the tank pressure. With the xenon gas flowing through the source (source not energized) a tank neutral pressure, $P_o = 4\times10^{-5}$ Torr was established. Initially a programmable power supply source/measure unit (electrometer) is used to monitor electron flux to a Langmuir probe (Lp) which is mounted near the face of the array. A bias of +30V is applied to the Lp relative to tank ground and the current flowing to the surface of the probe is carefully monitored. Next the filament current in the plasma source is gradually increased until the electrometer reads +0.4 milliamps indicating ionization of xenon gas neutrals is occurring and that a plasma is present. The Langmuir probe is swept in voltage to obtain the plasma parameters and the filament current to the plasma source is further adjusted until the Lp diagnostic parameters match the ionospheric conditions for the specified orbit. The plasma electron number densities and electron temperatures measured for the current tests were: $Ne = 4.0\times10^{-5}cm^{-3}$ and $Te = 0.89eV$, about the same values used the previous arcing tests in the vertical chambers.

For the arcing tests the three strings in each array are shorted and biased negative through a 10k ohm resistor to the a power supply and back to ground through a 1μF capacitor wired in parallel (see fig. 3). A current probe amplifier, current and voltage probes, a four channel 400 MHz digital storage oscilloscope, data acquisition and control software were used to record the arcs. Other miscellaneous equipment used in the tests included a quadruple mass spectrometer to record the levels of partial pressure for water vapor and other species in the vacuum system.

Arc Test Results

A plot of the partial pressure of water in the Vertical chamber, after three forty minute thermal cycles, is plotted in figure 1. The minimum partial pressure for water in the Vertical tank after three hundred hours pumping levels out at approximately 2 microTorr.[2] Therefore it was not necessary to proceed beyond 3 heating cycles for the vertical chamber tests. For comparison purposes note the over all level of reduction in the partial pressure of water is about 20 times less for the Teney vacuum chamber (after five complete thermal cycles) than is case for the Vertical chamber after three thermal cycles (see figs. 4(a) and 4(b)).

Table 1 depicts in tabular form the arcing results obtained for the diffusion pumped vertical chamber and the cryo-pumped Teney vacuum chamber. Figures 5(a) and 5(b) graphically depict the arcing threshold potential (or arc inception voltage) obtained before heating and after thermal cycling for sample 63 (the 300 micron thick cover slide array) tested in the Vertical and Teney vacuum chambers. Similarly figures 5(c) and 5(d) plot the arcing threshold potential before and after thermal cycling obtained for sample 62 (the 150 micron thick cover slide array). Note that the arc inception voltages plotted for the Vertical and Teney vacuum chamber tests of array samples 62 and 63 (figs. 5(a), 5(b), 5(c), and 5(d)) show that the arc inception voltage after heating is much more negative than is the case for the same samples before the arrays were heated.

Conclusions

The results from the thermal cycling tests appear to validate the arcing criterion that was forwarded earlier. The arcing criterion contends that the arc rate should drop as water is outgassed from the array due to heating. More importantly the arc inception voltage seems to be a better prognosticator in determining the effectiveness of thermal cycling on the outgassing of water from the array. In all cases the negative bias potentials recorded for initial arc inception voltage have been driven a great deal more negative after heating compared to the arc inception values recorded earlier before the arrays were heated. Furthermore the trend of lowering arc inception voltages after thermal cycling was observed in both the Vertical and Teney vacuum chamber tests.

As a result of the current measurements the amount of water in the chamber needs to be at or below the 1.6 microTorr minimum level after heating for the observed changes in the arc inception voltage to be seen. The observation of the required 1.6 microTorr level has caused us to rescind our earlier conclusion that the Vertical chamber was unable to remove enough water vapor to adequately test the arcing criterion. A careful reexamination of the data has revealed that the original thermal cycling tests were run in an inconsistent manner with changing plasma source and density parameters.[1, 2] The current tests were retested in the Vertical chamber with the same plasma source parameters, density and pressure set in the original thermal cycling tests of samples 62 and 63 run in the Teney vacuum chamber. Finally we believe we have demonstrated the effectiveness of the thermal cycling technique to passively outgas water from a solar array in an attempt to stave off arcing in LEO.

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Table 1.—Summary of arc rate test results for vertical and Teney chambers

	Diffusion Pumped Vertical Chamber				Cryogenic Teney Chamber			
	Strings #1, 2, & 3 (Sample 63) (300 micron thick cover slide)		Strings #4, 5, & 6 (Sample 62) (150 micron thick cover slide)		Strings #1, 2, & 3 (Sample 63) (300 micron thick cover slide)		Strings #4, 5, & 6 (Sample 62) (150 micron thick cover slide)	
	Bias	Arc Rate	Bias	Arc Rate	Bias	Arc Rate	Bias	Arc Rate
Before Heating:	-200 V	0 arcs in 30 minutes	-150 V	0 arcs in 15 minutes	-150 V	1 arc in 30 minutes	-110 V	0 arcs in 30 minutes
	-220 V	2 arcs in 30 minutes	-180 V	0 arcs in 15 minutes	-170 V	0 arcs in 30 minutes	-130 V	8 arcs in 30 minutes
	-240 V	4 arcs in 60 minutes	-200 V	2 arcs in 30 minutes	-200 V	4 arcs in 30 minutes	-150 V	21 arcs in 20 minutes
	-260 V	6 arcs in 30 minutes	-220 V	6 arcs in 38 minutes	-220 V	5 arcs in 30 minutes		
	-280 V	20 arcs in 30 minutes	-240 V	21 arcs in 30 minutes	-240 V	7 arcs in 30 minutes		
After Heating:	-220 V	0 arcs in 30 minutes	-200 V	0 arcs in 30 minutes	-150 V	0 arcs in 30 minutes	-150 V	1 arc in 30 minutes
	-240 V	0 arcs in 15 minutes	-240 V	4 arcs in 30 minutes	-170 V	0 arcs in 15 minutes	-170 V	0 arcs in 20 minutes
	-260 V	0 arcs in 20 minutes	-260 V	25 arcs in 20 minutes	-200 V	4 arcs in 30 minutes	-200 V	4 arcs in 30 minutes
	-280 V	0 arcs in 20 minutes	-270 V	15 arcs in 10 minutes	-220 V	5 arcs in 15 minutes	-220 V	9 arcs in 30 minutes
	-300 V	7 arcs in 30 minutes			-240 V	15 arcs in 5 minutes		
	-320 V	17 arcs in 30 minutes						
	-340 V	29 arcs in 30 minutes						

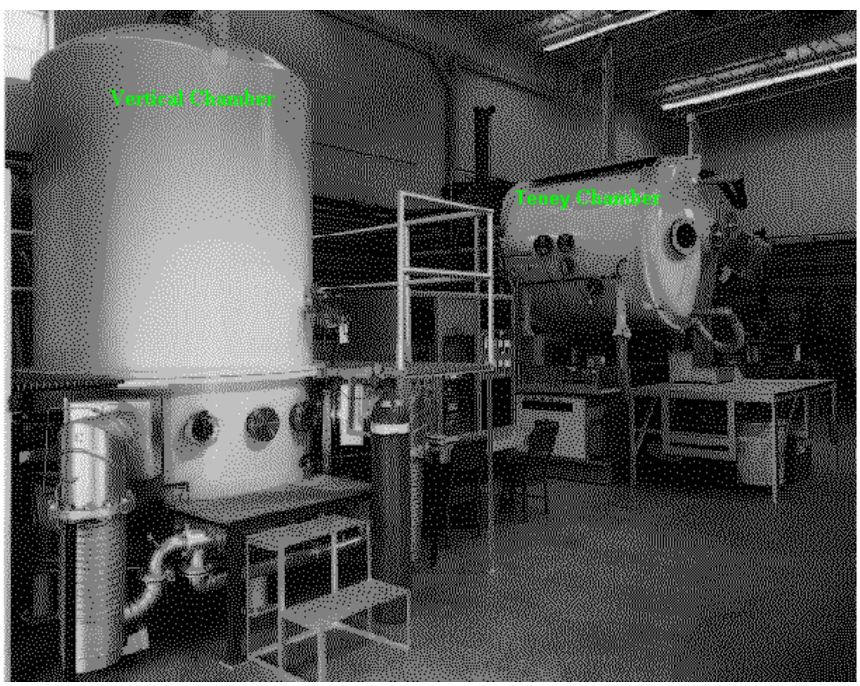

Figure 1.—NASA Glenn plasma interaction facility showing the 2.2×3 meter vertical chamber and the 1.8×2 meter Teney chamber.

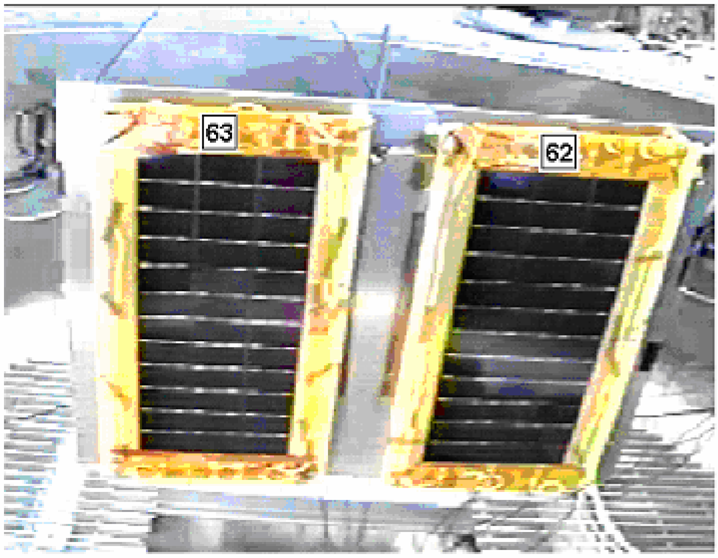

Figure 2.—Solar array samples and the heater plate assembly mounted in the vertical chamber prior to test.

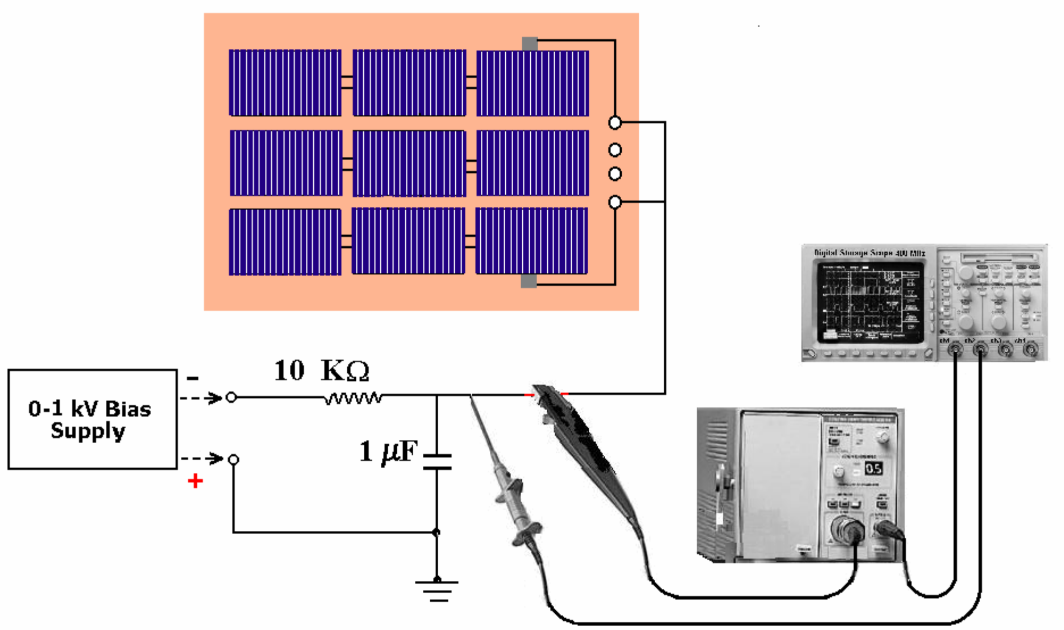

Figure 3.—R-C circuit and hardware used for detecting arcs on solar arrays.

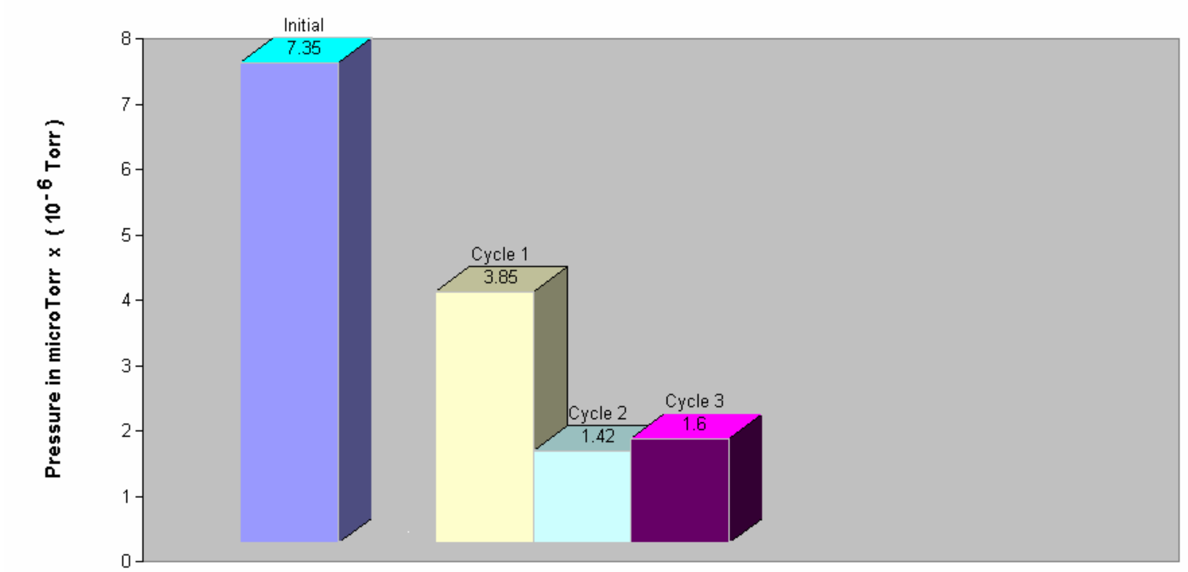

Figure 4(a).—Partial pressure of water in the vertical chamber after each heating cycle. The recorded pressures were obtained after the arrays cooled down to 11 °C.

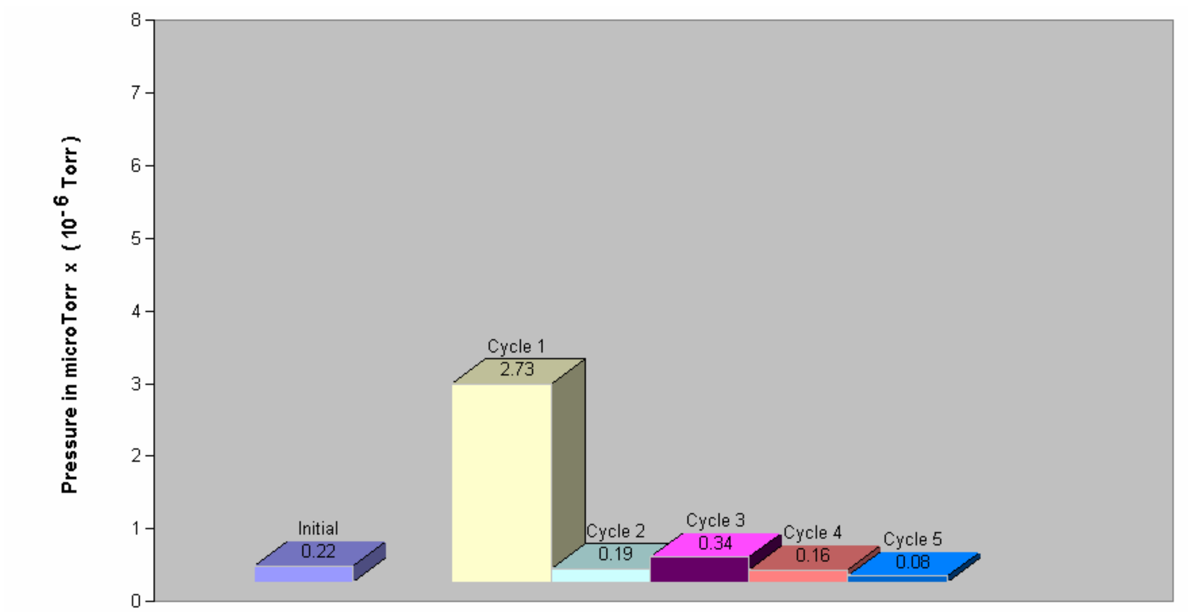

Figure 4(b).—Partial pressure of water in the Teney vacuum chamber after each heating cycle. The recorded pressures were obtained after the arrays cooled down to 11 °C.

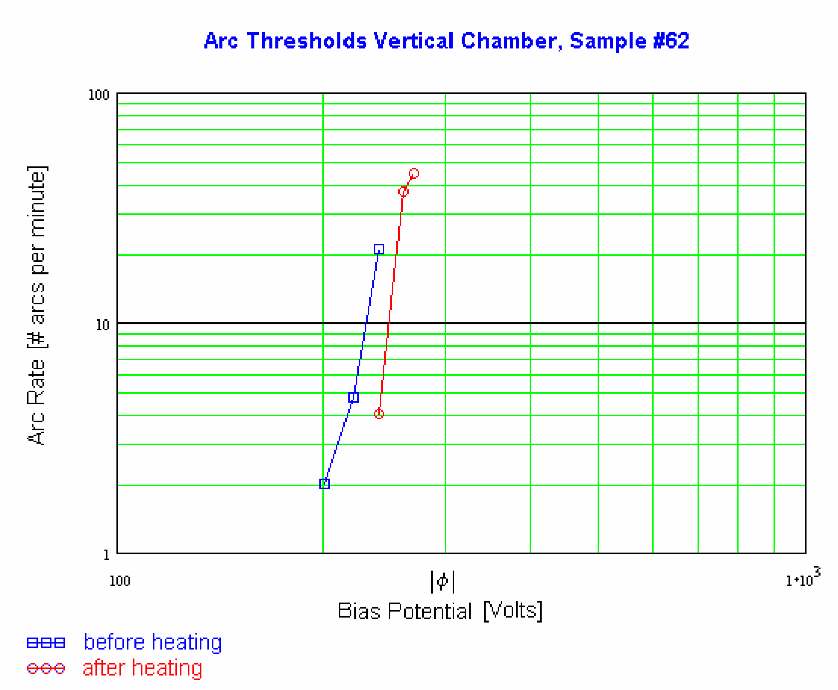

Figure 5(a).—Arc inception voltage before and after 3 heating cycles.

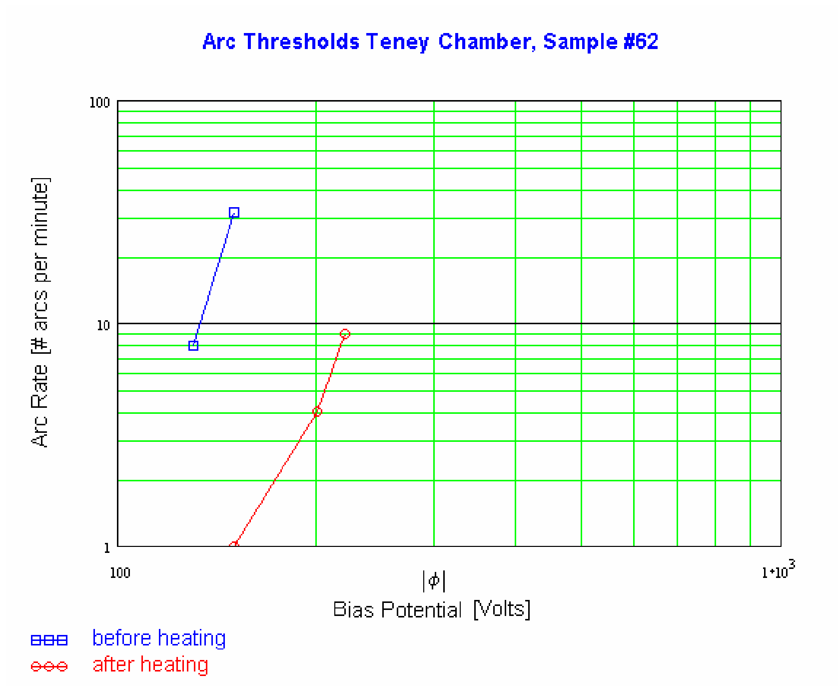

Figure 5(b).—Arc inception voltage before and after 5 heating cycles.

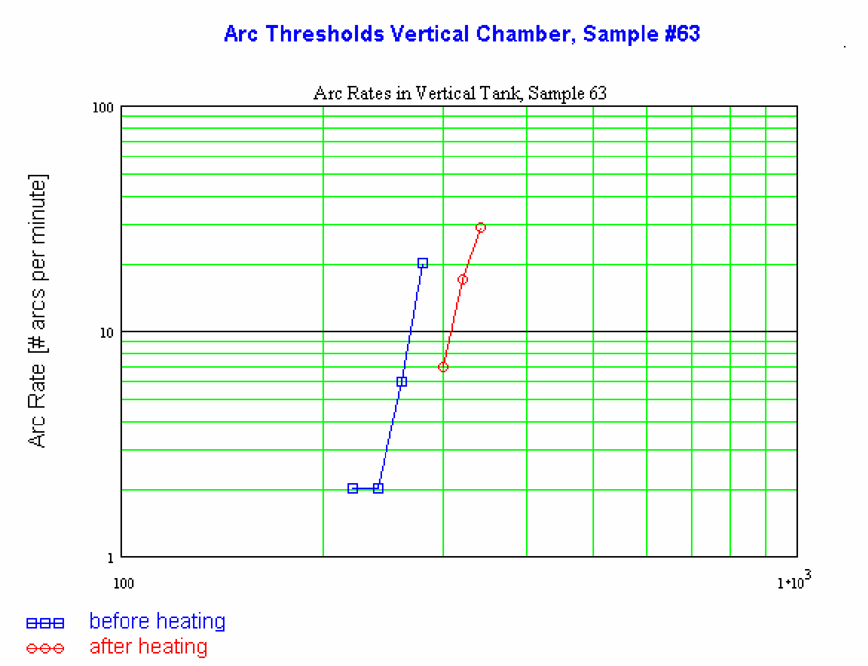

Figure 5(c).—Arc inception voltage before and after 3 heating cycles.

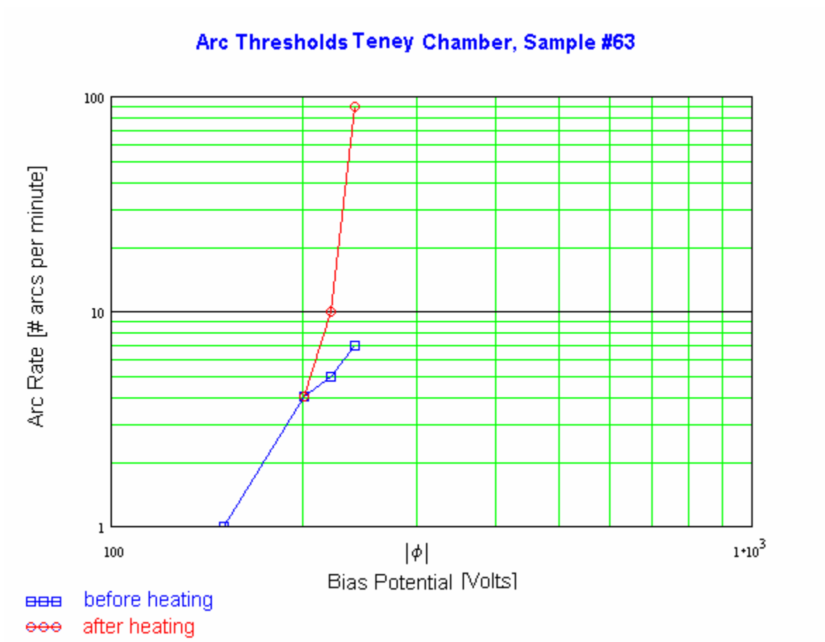

Figure 5(d).—Arc inception voltage before and after 5 heating cycles.

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13. ABSTRACT ***(Maximum 200 words)***

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