ATOMIC OXYGEN EFFECTS ON SEAL LEAKAGE

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ABSTRACT

Common Berthing Mechanism (CBM) provides the structural interface between separate International Space Station (ISS) elements, such as the Laboratory and Node modules. The CBM consists of an active and a passive half that join together with structural bolts. The seal at this interface is the CBM-to-CBM molded seal. The CBM-to-CBM interface is assembled on orbit, thus the seals can be exposed to the space environment for up to 65 hours. Atomic Oxygen/Vacuum Ultraviolet radiation (AO/VUV) in space is a potential hazard to the seals. Testing was conducted to determine the effect on leakage of the CBM-to-CBM seal material exposed to AO/VUV. The sealing materials were S383 silicone and V835 fluorocarbon material. Control samples, which were not exposed to the AO/VUV environment, were used to ensure that if any changes in leakage occurred, they could be attributed to the AO/VUV exposure. After exposure to the AO/VUV environment the leakage increase was dramatic for the fluorocarbon. This testing was a major contributing factor in selecting silicone as the CBM-to-CBM seal material.

INTRODUCTION

The International Space Station (ISS) is designed to allow long term continuous scientific experiments to be performed in the zero gravity environment of space. ISS consists of pressurized modules approximately 15 feet in diameter. The modules have attachment locations to allow the construction of ISS in stages. These attachment locations are accessed by berthing an active CBM (ACBM) to a passive CBM (PCBM). The ACBM is a ring of approximately 80 inches in diameter with various mechanisms attached (bolts, latches, guides, pins, etc.). The PCBM is also a ring of approximately 80 inches in diameter with nuts, guides, sockets, etc. attached. The ACBM contains all the powered components, the PCBM contains only non-powered components, including the CBM-to-CBM face seal. The CBM-to-CBM face seal consists of an aluminum metal retainer with rubber molded in the metal with heat and pressure. The ACBM and PCBM rings have flanges of approximately 3.5 inches that provide the seal surfaces for the CBM-to-CBM seal. The CBM-to-CBM interface is a field interface (i.e. the interface is put together on-orbit). The environment that the seals can experience prior to berthing the interface includes AO/VUV. Subsequent to this environmental exposure the seals need to provide atmospheric sealing for the berthed interface.

Many factors were analyzed in determining the material for this field interface. Factors included temperature, vacuum compatibility, AO/VUV stability, permeation, sealing force, and mechanical damage resistance. Silicone and fluorocarbon were initially selected as seal materials. Silicone material is generally better suited for low temperature effects, while fluorocarbon material generally provides good mechanical damage protection with low permeation. In order to evaluate the performance of both silicone and fluorocarbon seals exposed to the ISS environment, ground testing was conducted in which the seals were exposed to simulated AO/VUV under vacuum. Leak testing on o-rings was conducted pre and post exposure to monitor sealing performance. Various compression's were tested to simulate the gapping of the CBM-to-CBM interface. This paper presents the results of the seal leak testing.

TEST DESCRIPTION

The seals tested were o-rings in a dovetail groove. The seals were obtained from the same vendor that manufactures the CBM-to-CBM seals. The seals were S383 silicone and V835 fluorocarbon material. Control samples were used, which were not exposed to the AO/VUV environment. The control samples were used to ensure that if any changes in leakage occurred, it could be attributed to the appropriate cause (i.e. AO/VUV exposure).

Sample set up was as shown in figures 1 and 2. Leak testing was conducted per reference 1, Helium Mass Spectrometer Hood Test. O-ring samples were size -214 o-rings in a standard dovetail groove. The o-rings were not removed from their grooves until all testing was complete, to ensure that the o-rings saw minimal handling.

The seals were exposed to a synergistic effect of both atomic oxygen and vacuum ultraviolet radiation (AO/VUV) in the Atomic Oxygen Beam Facility (AOBF) located at NASA Marshall Space Flight Center. The exposure assembly is shown in figure 3 and the AO/VUV exposure system (AOBF schematic) is shown in figure 4. The Atomic Oxygen Beam Facility (AOBF) produces a 5 eV neutral atomic oxygen beam by placing a metal plate in contact with a magnetically (3 to 4 kilogauss) confined atomic oxygen plasma. The atomic oxygen plasma is produced by a radio frequency (RF) driven lower hybrid plasma source. A magnetron supplies 2kW of power at a frequency of 2.45 GHz to the center pin to produce the plasma. Because of the facility geometry, the atomic oxygen plasma is magnetically confined such that a 1 cm (0.39 in.) diameter. plasma column is produced on centerline of the test chamber. The plasma column interacts with an electrically biased metallic plate. The bias applied to the plate accelerates ions from the plasma to the plate. During the acceleration process, the ions gain energy equal to the difference in the plasma potential and the neutralizer plate bias. Once the ions hit the plate, they collect an electron from the metal lattice and become neutral. Following collision with the neutralizer plate, the atoms are reflected towards the test specimen at a fraction of their pre-collision energy. The fraction of energy lost by the reflected atoms is a function of the type of material used to make the neutralizer plate. Because the energy of the reflected atom depends on the plasma potential, which is inherently subject to slight variations, not all atoms will be accelerated by the same potential difference. Thus, the reflected atoms will have a slight energy distribution.

The atomic oxygen flux produced by the AOBF system ranges from 5×10^{15} atoms/sec-cm^2 to 1.7×10^{16} atoms/sec-cm^2. During production of the atomic oxygen plasma, the system produces electromagnetic radiation. This radiation is produced primarily during the dissociation and ionization process. Attempts to identify and quantify the radiation using a photodiode with appropriate narrow band filters indicated that the primary radiation line was 130 nm, the atomic oxygen resonant peak in the VUV region. The VUV intensity was determined to be nearly 200 times the sun's intensity averaged over the duty cycle. In order to eliminate possible magnetic interactions, appropriate shielding is placed around the diode.

Sample size for the AOBF is limited to 15.24 cm (6 in.) diameter. Thermocouples monitor the increase in sample temperature due to heat radiating from the neutralizer plate and magnets. Sample temperature ranges from 50 to 60 degrees C (122 to 140 F) depending on the duty cycle.

The AO exposure requirements come from reference 2, "The PCBM shall withstand a ram AO fluence of 5.0E21 atoms per cm^2 per year for the on-orbit exposure duration.
PCBM surfaces exposed less than 30 days shall withstand 4.4E19 atoms per cm^2 per day AO ram fluence." The integrated ultraviolet irradiance at one astronomical unit is 118 Watts per square meter.

The maximum predicted hours of on-orbit exposure for the CBM-to-CBM seal is 65 hours for Pressurized Mating Adapter 2 (PMA2), the next most exposure is PMA3 at 25 hours.

TEST CONDUCT

Sample preparation

1. Inspected seals for defects and seal groove for radial scratches.
2. Inspected groove and seal for contamination (performed in a flow bench). Cleaned with ethyl alcohol or denatured alcohol.
3. Installed seal into groove (performed in a flow bench).
4. Measured crown height.
5. Inspected exposed seal and seal surface for contamination (performed in a flow bench). Cleaned with ethyl alcohol or denatured alcohol as required.
6. Assembled fixture with no shim, verified no gap with feeler gauge on outside of seal (performed in a flow bench).
7. Installed helium containment hood (performed in a flow bench).
8. Attached fixture to leak detector.
9. Calibrated system.
10. Performed leak test.
11. Disassembled fixture to allow for next shim installation (performed in a flow bench).

The initial condition was performed for no gap, then steps 6-11 were repeated with a .007" shims, then .010" shims for silicone and .015" shims for fluorocarbon. The same sample was tested at all three gaps against the same sealing surface before going to next sample. The sample was oriented the same during each test.

TEST FLOW

Non-lubricated samples

1. Baseline leak tested fluorocarbon and silicone samples.
2. Exposed fluorocarbon and silicone samples to AO/VUV.

3. Leak tested fluorocarbon and silicone samples.
4. Exposed silicone samples to additional AO/VUV.
5. Leak tested silicone samples.

Lubricated samples

(new samples different from non-lubricated samples)
1. Lubricated samples with a wet shinny appearance, with no clumps. Braycote 601 lubricant was used.
2. Silicone samples were compressed five times each and the lubrication track on the sealing surface was removed between each compression. This was to simulate multiple on-orbit berths (Pressurized Mating Adapter 2 (PMA2) has a maximum of 6 berths).
3. Baseline leak tested fluorocarbon and silicone samples.
4. Exposed fluorocarbon and silicone samples to AO/VUV.
5. Leak tested fluorocarbon and silicone samples.

RESULTS

Non-lubricated

The non-lubricated samples test results are shown in table 1. Baseline leakage is tabulated for the three different compression values, and then the post exposure leakage is shown, and finally the exposure environment. The silicone samples were exposed to additional AO/VUV. Additional exposure leakage values and exposure environment are also tabulated in table 1. Equivalent hours of exposure for the fluorocarbon seals was 18 to 23 hours and 10 to 181 hours for the silicone samples. Compression values are +/-3% accuracy and VUV values listed are minimum values. The post exposure leakage indicates that the fluorocarbon had a dramatic increase in leakage. Post exposure visual examination of the fluorocarbon samples revealed a gray ash appearance, which was not present in the control sample. Plots of leak rate versus equivalent exposure time for the silicone samples (figures 5 and 6) are included. A second order linear regression line for the data indicates excellent linear correlation. Control samples were sample number 3, and indicated excellent repeatability of leak testing. As expected the less compression that the seals experienced resulted in higher leakage.

Lubricated

The lubricated samples test results are shown in table 2. Baseline leakage is tabulated for the three different compression values, and then the post exposure leakage is shown, and finally the exposure environment. Equivalent hours of exposure for the silicone samples was 43 to 45 hours and 10 to 12 for the fluorocarbon samples. Compression values are +/-3% accuracy and VUV values listed are minimum values. The post exposure leakage indicates that the fluorocarbon had a dramatic increase in leakage. Post exposure visual examination of the fluorocarbon samples revealed a gray ash appearance, which was not present in the control sample. Plots of leak rate versus equivalent exposure time for the silicone samples (figures 5 and 6) are included. Silicone samples reveal a small degradation of leakage and following the exposure. The lubricated samples generally have less leakage degradation. Control samples were sample number 3, and indicated excellent repeatability of leak testing. As expected the less compression that the seals experienced resulted in higher leakage.

CONCLUSIONS

The non-lubricated silicone S383 leakage degradation varies linearly with the amount of AO/VUV exposure. This linear relationship can be used for exposures less than 181 hours for S383 silicone. Silicone exposure should be minimized to ensure that leakage will not exceed requirements. Fluorocarbon V835 was dramatically effected by AO/VUV exposure and should not be used in space flight for maintaining pressure when exposed to this environment.

REFERENCES

1. *ASME Boiler and Pressure Vessel Code*, Section V, Article 10, 1992.
2. *Prime Item Development Specification for Passive Common Berthing Mechanism*, S683-28943 paragraph 3.2.5.18, rev D.

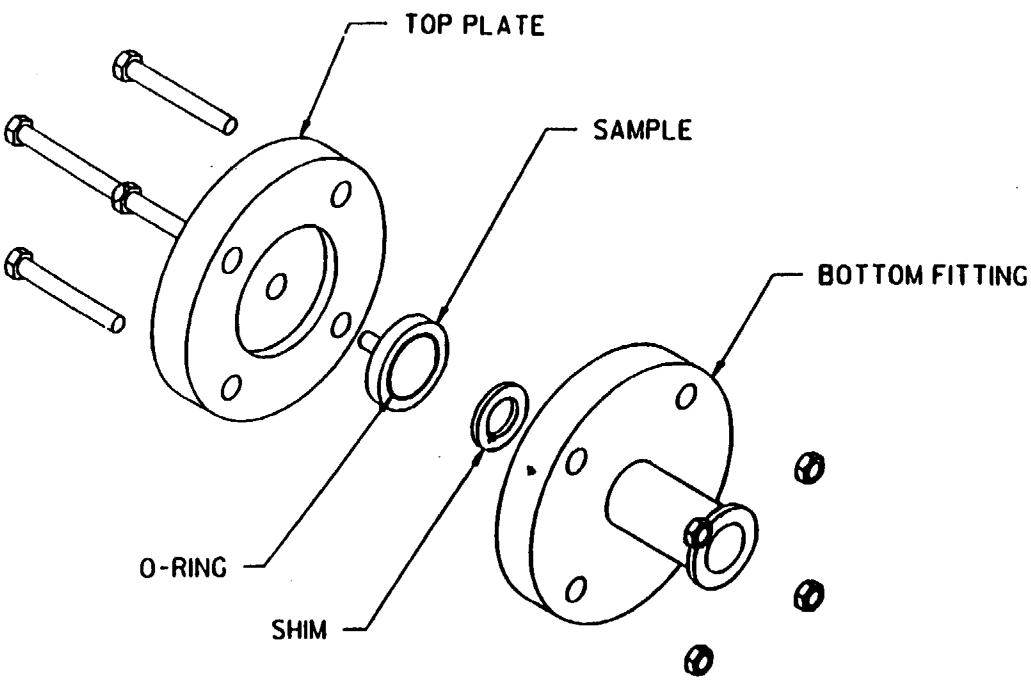

FIGURE 1
Exploded View of Sample
scale: none

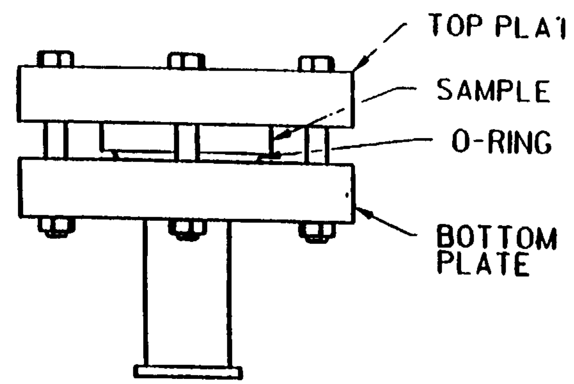

Figure 2
Assembly of Sample
scale: none

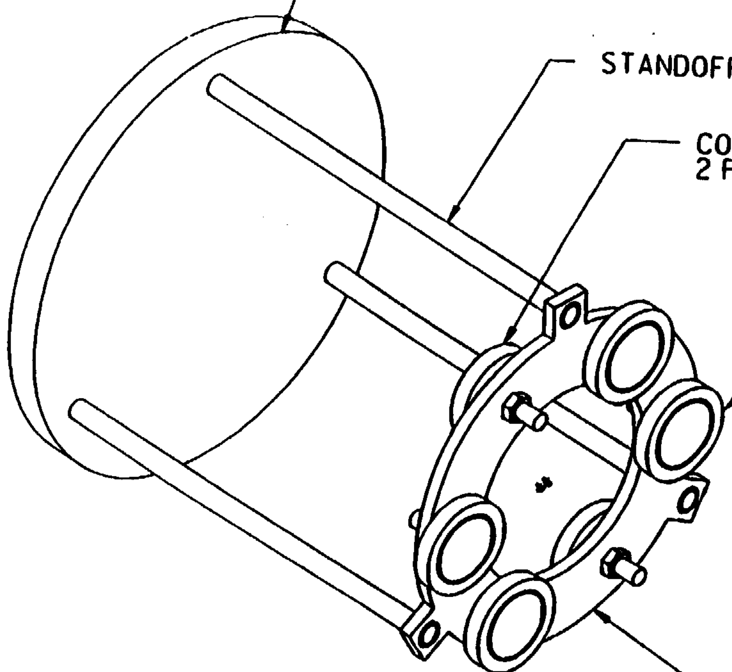

Figure 3
Exposure Assembly
scale: none

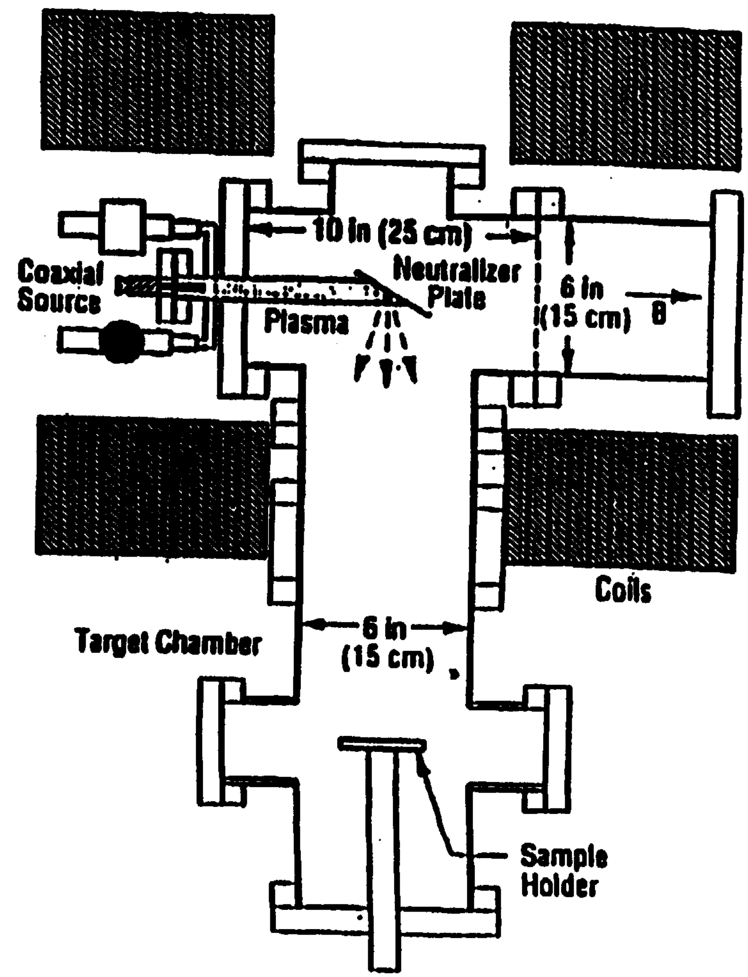

Figure 4
AO/VUV Exposure System
scale: none

Table 1 Non-Lubricated Seals

Pre-exposure Baseline Leakage (atm cc/sec He)									
Sample identification	Leak Rate	% Compression		Leak Rate	% Compression		Leak Rate	% Compression	
Fluorocarbon 1	2.20E-06	16.0		2.60E-06	11.0		1.10E-05	5.0	
Fluorocarbon 2	2.30E-06	16.0		2.60E-06	11.0		6.20E-06	5.0	
Fluorocarbon 3	1.70E-06	16.0		3.90E-06	11.0		1.20E-05	5.0	
Silicone 1	1.80E-05	12.0		2.30E-05	7.0		2.60E-05	4.0	
Silicone 2	1.60E-05	14.0		2.20E-05	9.0		2.60E-05	7.0	
Silicone 3	2.70E-05	13.0		3.20E-05	8.0		3.70E-05	6.0	

Exposure 1 Environment			
Sample identification	AO Fluence (atoms/cm^2)	Equivalent Hours	VUV (watts-hrs/m^2)
Fluorocarbon 1	4.24E+19	23.1	2729.0
Fluorocarbon 2	3.44E+19	18.8	2214.1
Fluorocarbon 3	0.0	0.0	0.0
Silicone 1	1.88E+19	10.3	1210.0
Silicone 2	1.95E+19	10.6	1255.1
Silicone 3	0.0	0.0	0.0

Post-exposure 1 Leakage									
Sample identification	Leak Rate	% Compression	% Change in Leak rate	Leak Rate	% Compression	% Change in Leak rate	Leak Rate	% Compression	% Change in Leak rate
Fluorocarbon 1	1.90E-03	16.0	-86263.6	2.70E-03	11.0	-103746.2	5.40E-03	5.0	-48990.9
Fluorocarbon 2	1.10E-03	16.0	-47726.1	1.50E-03	11.0	-57592.3	3.60E-03	5.0	-57964.5
Fluorocarbon 3	1.00E-06	16.0	41.2	3.30E-06	11.0	15.4	1.20E-05	5.0	0.0
Silicone 1	1.90E-05	12.0	-5.6	2.60E-05	7.0	-13.0	3.70E-05	4.0	-42.3
Silicone 2	3.00E-05	14.0	-87.5	3.10E-05	9.0	-40.9	7.40E-05	7.0	-184.6
Silicone 3	1.60E-05	13.0	40.7	2.00E-05	8.0	37.5	2.30E-05	6.0	37.8

Exposure 1 and 2 Environment			
Sample identification	AO Fluence (atoms/cm^2)	Equivalent Hours	VUV (watts-hrs/m^2)
Silicone 1	2.70E+20	147.3	17378.2
Silicone 2	3.32E+20	181.1	21368.7
Silicone 3	0.0	0.0	0.0

ost-exposure 1 and 2 Leakage									
Sample identification	Leak Rate	% Compression	% Change in Leak rate	Leak Rate	% Compression	% Change in Leak rate	Leak Rate	% Compression	% Change in Leak rate
Silicone 1	5.00E-05	12.0	-177.8	6.40E-05	7.0	-178.3	1.80E-04	4.0	-592.3
Silicone 2	1.40E-04	14.0	-775.0	4.30E-04	9.0	-1854.5	8.60E-04	7.0	-3207.7
Silicone 3	1.50E-05	13.0	44.4	1.90E-05	8.0	40.6	2.20E-05	6.0	40.5

Table 2 Lubricated Seals

Pre-exposure Baseline Leakage

Sample Identification	Leak Rate	% Compression		Leak Rate	% Compression		Leak Rate	% Compression
Fluorocarbon 1	2.10E-06	15.0		3.00E-06	10.0		4.00E-06	4.0
Fluorocarbon 2	2.40E-06	15.0		3.00E-06	10.0		3.90E-06	4.0
Fluorocarbon 3	1.90E-06	15.0		2.90E-06	10.0		3.00E-06	4.0
Silicone 1	1.90E-05	11.0		2.40E-05	5.0		2.60E-05	3.0
Silicone 2	1.80E-05	11.0		2.20E-05	5.0		1.80E-05	3.0
Silicone 3	1.10E-05	10.0		2.40E-05	5.0		2.60E-05	2.0

Exposure 1 Environment

Sample Identification	AO Fluence (atoms/cm^2)	Equivalent Hours	VUV (watts-hrs/m^2)
Fluorocarbon 1	1.82E+19	9.9	1171.4
Fluorocarbon 2	2.24E+19	12.2	1441.7
Fluorocarbon 3	0.0	0.0	0.0
Silicone 1	8.20E+19	44.7	5277.8
Silicone 2	7.90E+19	43.1	5084.7
Silicone 3	0.0	0.0	0.0

Post-exposure 1 Leakage

Sample Identification	Leak Rate	% Compression	% Change in Leak rate	Leak Rate	% Compression	% Change in Leak rate	Leak Rate	% Compression	% Change in Leak rate
Fluorocarbon 1	4.70E-04	15.0	-22281.0	3.50E-03	10.0	-116566.7	1.60E-03	4.0	-39900.0
Fluorocarbon 2	7.30E-04	15.0	-30316.7	1.00E-03	10.0	-33233.3	2.20E-03	4.0	-56310.3
Fluorocarbon 3	1.50E-06	15.0	21.1	2.10E-06	10.0	27.6	2.30E-06	4.0	23.3
Silicone 1	3.10E-05	11.0	-63.2	4.10E-05	5.0	-70.8	4.20E-05	3.0	-61.5
Silicone 2	2.30E-05	11.0	-27.8	4.00E-05	5.0	-81.8	4.40E-05	3.0	-144.4
Silicone 3	1.80E-05	10.0	-63.6	2.20E-05	5.0	8.3	2.60E-05	2.0	0.0

Figure 5
Silicone Sample 1

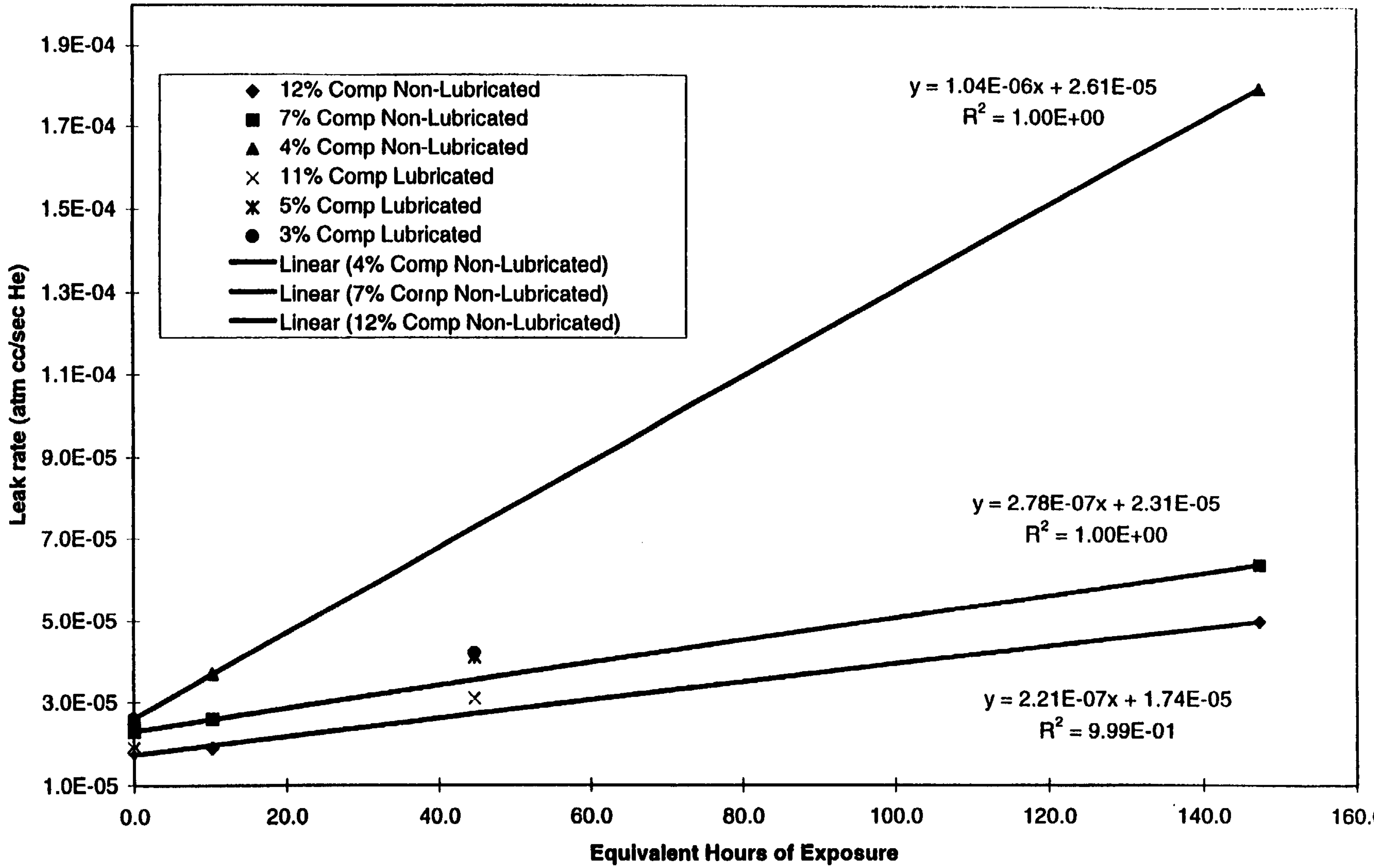

Figure 6
Silicone Sample 2