Pressure Dependence of Insulator-Insulator Contact Charging

The mechanism of insulator-insulator triboelectric (contact) charging is being studied by the Electrostatics and Surface Physics Laboratory at KSC. The hypothesis that surface ion exchange is the primary mechanism is being tested experimentally. A two-phase model based on a small partial pressure of singly charged ions in an ambient ideal gas in equilibrium with a submonolayer adsorbed film will provide predictions about charging as a function of ion mass, pressure, temperature, and surface adsorption energy. Interactions between ions will be considered in terms of coulombic and screened potential energies. This work is yielding better understanding of the triboelectrification of insulators, which is an important problem in space exploration technology. The work is also relevant to important industrial processes such as xerography and the application of paints and coatings. Determining a better understanding of the fundamental mechanism of insulator-insulator triboelectrification will hopefully lead to better means of eliminating or at least mitigating its hazards and enhancing its useful applications.

Surface impurities, which can be mostly ionic in nature, can play a role in the charging of insulators. Ion transfer in metal-insulator charging has been advocated by several researchers to account for charge exchange. Ions can exist on the surface of an insulator either in weak bonds due to intermolecular forces while residing in vibrational energy states or as solvated ions in a thin surface water layer.

Since atmospheric pressure and surface moisture layers play a major role in surface charging, a physical model is presented in which the surface of the insulator is in equilibrium with its external environment. Equilibrium is used because charge transfer occurs rapidly during triboelectrification. The surface is modeled as having localized states with adsorption energy, ξ_0, for the surface particles. The particles are considered to be a vapor of noninteracting ions of single polarity in equilibrium with an adsorbed submonolayer on the surface. The chemical potential of the vapor is determined using the grand canonical ensemble and then equated to the chemical potential of the submonolayer to determine vapor pressure. By assigning a charge (assuming single ionization) to the vapor particles, the surface charge resulting from the adsorbed monolayer can be calculated as a function of pressure. Including the effective electrostatic potential felt by the gas-phase particles from the surface charge gives an equation for surface charge density in terms of ion mass, pressure, adsorption energy, and temperature:

$$\sigma = \frac{q_e N}{A} \frac{1}{\frac{E_2\left({}^{a}\!/_{z_0}\right)}{P}\left(\frac{k_B T}{\lambda^3}\right)e^{-\xi_0/k_B T} + 1}, \tag{1}$$

where N is the total number of surface states available, A is the surface area, P is the vapor pressure, $k_B T$ is the particles' thermodynamic energy, ξ_0 is the adsorption energy, and $\hbar$ is Planck's constant divided by 2π. α is a characteristic distance found by dividing the electrostatic energy by the thermal energy of a particle and solving for the radius called the Bjerrum length, λ is the thermal length, and z_0 is the distance from the surface. $E_2(\alpha/z_0)$ is the second-order $E_n(x)$ function with α/z_0 as the argument.

Letting $\sigma_0 = q_e \frac{N}{A}$ and $P_0 = \left(\frac{k_B T}{\lambda^3}\right) E_2\left(\alpha/z_0\right) e^{-\xi_0'/k_B T}$, we can put Eq. (1) into a dimensionless form.

$$\frac{\sigma}{\sigma_0} = \frac{1}{1+\frac{P_0}{P}}, \tag{2}$$

which is an electrostatic version of a Langmuir isotherm for ions in equilibrium between an adsorbed surface phase and a gas phase.

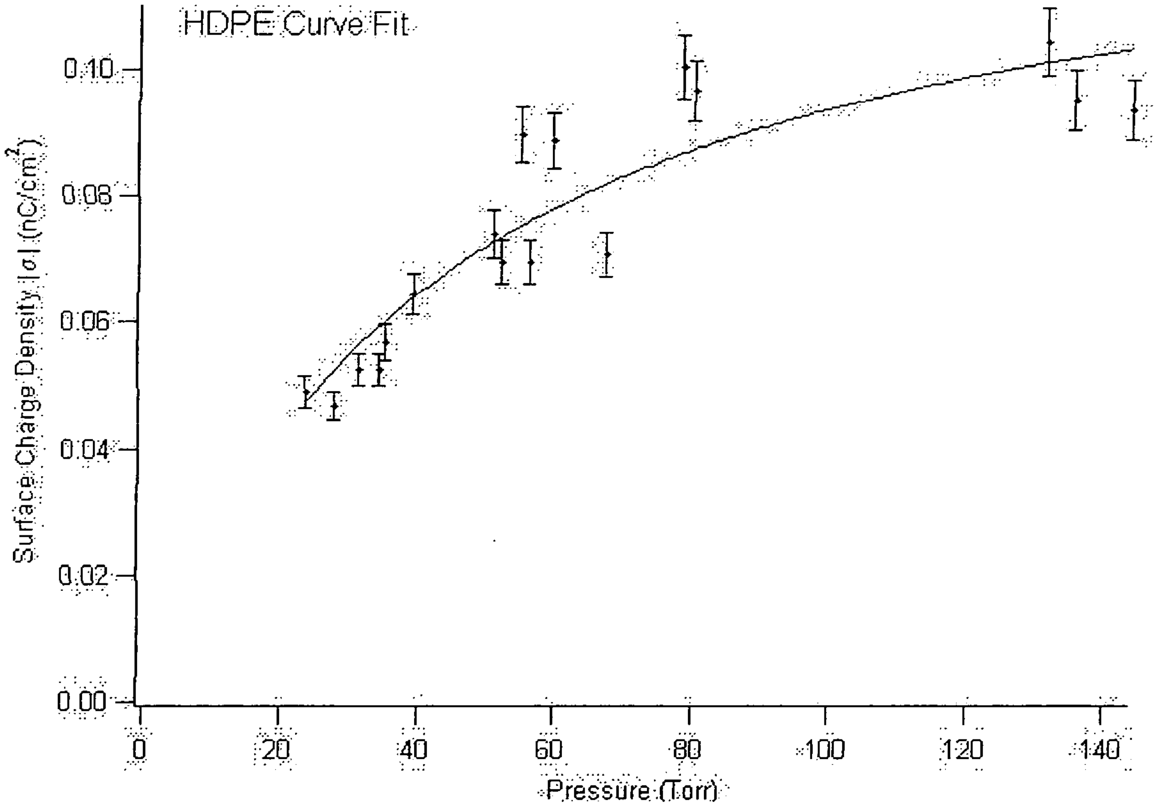

Figure 1. Surface charge as a function of pressure for HDPE data curve fit to the model equation.

Experimental surface charge versus pressure data was taken for several polymers after triboelectrification using a wool wheel. This data was curve-fit to the model equation for each polymer. An example of these curve fits is shown for high-density polyethylene (HDPE) in Fig. 1.

Expanded curve fit data for various polymers were calculated letting surface adsorption energy and the total number of surface states, N, float. These data are summarized in table 1.

Electrical induction charging consists of using a charged metal plate to place electrons on a surface. Several polymers from the test group listed in table 1 were charged this manner. It was found that lowered pressure did not remove the surface charge as it did for triboelectrification. This indictates that the charge exchange mechanism for triboelectrification between polymers is mostly ion exchange.

TABLE 1

Summary of Curve Fit Values of Adsorption Energy and Total Number of Surface States

Polymer	ξ_0 (eV)	N ($\times 10^9$)
HDPE	$-0.396 \pm_{0.0028}^{0.0087}$	5.96 ± 0.532
LDPE	$-0.41 \pm_{0.0075}^{0.0107}$	6.09 ± 0.768
PTFE (all samples)	$-0.366 \pm_{0.0109}^{0.0083}$	18.4 ± 2.45
PTFE (samples 1 & 2)	$-0.341 \pm_{0.0058}^{0.0051}$	4.79 ± 0.444
PTFE (samples 3-10)	$-0.35 \pm_{0.0043}^{0.0085}$	27.9 ± 3.59
Polycarbonate (all samples)	$-0.332 \pm_{0.0148}^{0.0098}$	0.353 ± 0.0557
Polycarbonate (corner points only)	$-0.391 \pm_{0.0185}^{0.0114}$	1.21 ± 0.162
Polycarbonate (sample 1)	$-0.418 \pm_{0.0035}^{0.0033}$	2.18 ± 0.061
Polycarbonate (sample 2)	$-0.402 \pm_{0.0026}^{0.0019}$	0.847 ± 0.02
Polycarbonate (sample 3)	$-0.42 \pm_{0.0014}^{0.0016}$	0.313 ± 0.00362
Polycarbonate (sample 9)	$-0.409 \pm_{0.0006}^{0.0014}$	0.675 ± 0.00596
Styrene (corner points only)	$-0.387 \pm_{0.0062}^{0.0055}$	14.2 ± 0.726
PVC (corner points only)	$-0.371 \pm_{0.0106}^{0.008}$	14.2 ± 1.52
PVC (sample 1)	$-0.374 \pm_{0.0032}^{0.0032}$	4.96 ± 0.181
PVC (sample 5)	$-0.379 \pm_{0.0009}^{0.0001}$	10.5 ± 0.0962
PVC (sample 8)	$-0.376 \pm_{0.0015}^{0.0023}$	15.1 ± 3.45

Key accomplishments:

- Studied initial surface charge density versus pressure experiments on polymers.
- Revised preliminary model to include effective coulombic and screening potentials.
- Completed expanded triboelectric experiments on polymers.
- Completed induction experiments on polymers.

Key milestones:

- Continue corona experiments
- Perform metal-insulator triboelectric experiments.
- Continue to improve theoretical model and determine its physical limitations.

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