

Temperature Effects on Polymer-Carbon Composite Sensors

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Summary

At the Jet Propulsion Laboratory (JPL) we have investigated the effects of temperature on polymer-carbon black composite sensors. While the electrical properties of polymer composites have been studied¹, with mechanisms of conductivity described by connectivity and tunneling², it is not fully understood how these properties affect sensor characteristics and responses. Baseline resistance and sensor response as a function of temperature were measured for six selected polymer-carbon black composites. For these six composites, sensor baseline resistance decreased with increasing temperature and the sensor responses to both methanol and water decreased as the temperature increased. Subsequently, varied carbon loadings and polymer molecular weight of the composites were studied to determine how these properties influence the temperature effects of these materials. The noticeable changes in sensor properties can be explained by a change in conduction mechanism and is particularly apparent for different carbon loadings.

Motivation

The JPL Electronic Nose (ENose)³ uses polymer-conductor composite sensing materials to detect a range of vapor phase compounds⁴. The sensing materials are polymer-carbon black composites that change in conductivity upon interaction with vapor phase molecules. The response of a sensor to an analyte is measured as the relative change in resistance, dR/R_0 ; responses to an array of weakly specific sensors with varying polymer compositions/functional groups are used to create a fingerprint, or pattern across the array. The fingerprint is used to identify and quantify the analyte inducing the response. Sensor response may be affected by external conditions such as pressure, humidity⁵, and temperature. These studies have been undertaken with a view to integrating external effects into models of sensor-analyte interaction to improve sensor data analysis with compensating algorithms.

¹ M. Narkis, A. Ram, F. Flashner, "Electrical properties of carbon black filled polyethylene", *Polymer Engineering & Science*, vol. 13, n. 5, pg. 462, 1973.

² Edited by Enid Keil Sichel, "Carbon Black-Polymer Composites: The Physics of Electrically Conducting Composites", Marcel Dekker, Inc., New York, 1982

³ <http://enose.jpl.nasa.gov>

⁴ M.A. Ryan, M.L. Homer, M.G. Buehler, K.S. Manatt, F. Zee, "Monitoring the Air Quality in a Closed Chamber Using an Electronic Nose", *Proceedings of the 27th International Conference on Environmental Systems*, Lake Tahoe NV July 14-17, 1997

⁵ A. M. Manfreda, "Elucidating Humidity Dependence of the Jet Propulsion Laboratory's Electronic Nose Polymer-Carbon Composite Sensors", California State Polytechnic University, Pomona (thesis, May 2002).

Results

Resistance changes as a function of temperature were measured for six polymer-composite sensors in flowing dry air, in the temperature range 28-36°C in 2°C steps. In each case the baseline resistance decreases with increasing temperature. The increase in conductivity is a thermally activated process and may be linked to tunneling. Sensor response to methanol [10-100ppm] and water [7.5-150 ppm] on the same set of sensors was measured at 28°C, 32°C and 36°C. Figure 1 shows a characteristic decrease in sensor response with increasing baseline temperature for a 100 ppm exposure of methanol. Similarly, decreases in response as carbon load increases in polymer composite sensors have been noted in our laboratory.

As decreases in response as carbon load increases in polymer composite sensors have been noted in our laboratory, sensor responses for different polymers with varying molecular weights and varying carbon loadings were measured under the same conditions as in the first experiment. Polyethylene oxide (PEO), 20k M.W. sensors with lower carbon load show a decrease in resistance with an increase in temperature, whereas the highest carbon loaded sensors exhibit an increase in resistance with an increase in temperature (Figure 2). In other polymer composites, apparent changes in conduction mechanisms are based on temperature change and percolation threshold⁶. At higher molecular weights, all measured sensors showed a decrease in resistance with increasing temperature. This may indicate that the higher molecular weight sensors are within the majority tunneling regime. Modeling results for these sensors has tied percolation threshold with the degree of polymer entanglement around carbon black particles, which are both related to molecular weight of the polymer and corresponding electrical properties. It must be stressed, that although a decrease in sensor response could be attributed to temperature effects, a combination of factors such as changes in surface energy, analyte-polymer interactions, and partition coefficients, may govern the entire phenomenon.

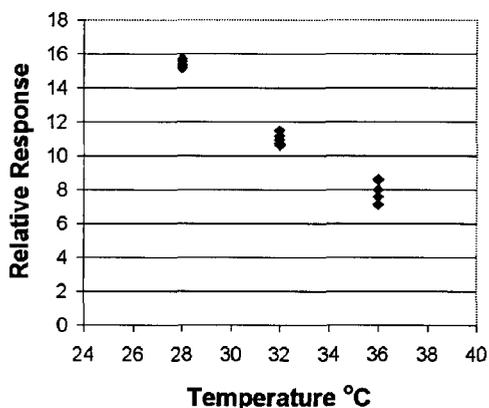


Figure 1 – Decreasing Poly N-vinyl pyrrolidone (360k M.W., 20 wt.% carbon) sensor response to different baseline temperatures. Sensor was held at different baseline temperatures under dry nitrogen and exposed to 100 ppm methanol (5 exposures).

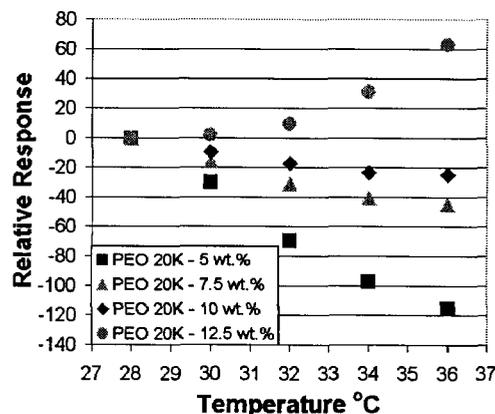


Figure 2 – Baseline resistance of PEO sensors as a function of temperature. Each sensor temperature was held at 28°C (baseline with dry air) and stepped 2°C to 36°C.

⁶ D. Stauffer (ed.), "Introduction to Percolation Theory", Taylor and Francis, London, 1985.