Activated Carbon Cloth in Electrical Applications

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Introduction

It has been known since the beginning of the century that activated carbon is electrically conductive and possesses the electrical properties of a semiconductor.[1] Applications utilizing the electrical properties of activated carbon have been limited due to the non-contiguous nature of granular activated carbon products. Activated Carbon Cloth (ACC) provides a contiguous carbon form that is ideally suited for use in electrical applications. Studies have shown that ACC exhibits good electrical storage capacity; can be effectively heated using resistance heating; exhibits extremely fast heat-up and cool-down rates; can be maintained at any steady state temperature with good temperature uniformity; and shows no electrical degradation over thousands of heating and cooling cycles. In tests with adsorbed species, electrically heated ACC was shown to rapidly remove nearly all adsorbed species. These unique properties of ACC are leading to a variety of novel applications related to the electrically conductive nature of this material.

Conductive Nature of Carbon

Carbon must be formed into an organized "graphitic like" structure to be electrically conductive. This transformation with ACC occurs during the thermal manufacturing process. A carbonized (or charred) sample of cloth exhibits no electrical conductivity. Once the sample is thermally activated, the organized carbon structure is formed and the cloth becomes electrically conductive. The electrical conductivity of the ACC decreases with increased activation time. Reductions in electrical conductivity approaching 50% can be achieved depending upon the length of the thermal activation step.

Experimental

Two types of ACC produced by Charcoal Cloth International were investigated in this study. These samples (called FM1-250 and FM5-250) differ only in terms of the thickness of the weave of the fabric. FM5-250 possesses a thicker weave pattern than FM1-250, approximately a factor of two difference in the density of the materials. Both fabrics utilize the same cloth fibers. All carbon cloth samples were assembled by attaching metal electrical leads to opposite ends of the samples. The cloth samples were secured to a frame that held the samples about four inches above the laboratory bench. A standard voltmeter was used to measure voltage, resistance and current. For resistive heating experiments, an alternating current rheostat power supply or temperature controller was used to apply voltage to the samples. Temperatures were measured using an infrared thermometer and/or surface thermocouples.

Electrical Connections to Cloth

Electrical connections/leads were found to be critical to good electrical performance of ACC. Electrical leads were attached to opposite ends of the cloth and were at least the same length as the cloth sample to ensure uniform current transfer. The width and thickness of the electrical leads were found to have no relevance to the electrical performance of the cloth samples. It was critical that the electrical leads were made of a material that was orders of magnitude more conductive than the cloth. Aluminum, stainless steel and copper were investigated in this study. The difference in conductivity between the electrical lead and the cloth ensured that the current would be immediately distributed throughout the electrical lead when a voltage was applied to the sample. Immediate current distribution in the electrical lead was important to uniform current flow throughout the cloth sample.

Conductivity/Resistance of ACC

The conductivity of a material is simply the inverse of its resistance. The resistance of ACC is difficult to measure accurately. The method utilized in this study was based on surface resistivity[2] with a one inch distance between the probe electrodes. Typical resistance values for FM1-250 and FM5-250 ranged from 8 to 1 ohms/square, respectively. Resistance measurements of the cloth samples were found to be a function of cloth type, number of cloth layers and the humidity level. Since ACC acts like a semiconductor, the resistance was found to be a function of temperature with the resistance decreasing linearly with increased temperature. The resistance of FM1-250 and FM5-250 decreased about 15% below its ambient value per every 55 °C increase in temperature.

Resistive Heating of ACC

ACC can be effectively heated using electrical resistance heating (also called Joule Heating). Resistive heating was accomplished by applying a constant voltage source (either AC or DC) to the electrical leads on opposite ends of the cloth. A variety of different cloth scenarios (multiple layers and different sizes) were investigated. The voltage and power requirements for these different scenarios were correlated to linear functions of temperature, thereby, providing a predictive capability for the resistive heating performance of ACC in nearly any application.

ACC can be maintained at a desired steady state temperature by applying a constant voltage to the sample. ACC exhibits extremely fast heat-up and cool-down rates. The cloth can be heated to temperatures exceeding 400 °C in seconds and cools just as quickly back to ambient temperatures. This fast cool-down rate provides a safety benefit to a process and should improve adsorption performance when the cloth is back on line after regeneration since physical adsorption is more effective at lower temperatures.

The temperature uniformity across the surface of cloth samples was investigated using a handheld infrared thermometer. Square and rectangular shaped samples of cloth exhibited temperature variation of roughly +/- 10 °C from the steady state temperature measured at the center of the sample. This temperature variation tended to decrease the longer the cloth was heated during a heating cycle. Temperatures tended to be hotter at the hot electrical lead (black) compared to the neutral electrical lead (white).

The effect of temperature cycling on the long-term performance and durability of activated carbon cloth was investigated. A sample of FM1-250 was cycled for 5 minutes at 120 °C and 5 minutes at room temperature. The sample was tested for more than 5000 temperature cycles. The electrical properties of the sample were tested on a regular basis. The sample showed no measurable degradation in electrical performance. At the completion of testing, the sample showed no visible signs of wear or tear and looked exactly as it did when testing began.

Effect of Adsorbed Components

The effect of adsorbed components on the resistive heating performance of ACC was investigated. A sample of FM1-250 was loaded with Toluene to 16 grams adsorbed per 100 grams of cloth. Resistance measurements of the sample before and after being loaded with Toluene showed no detectable electrical change to the cloth sample. Additionally, the loaded Toluene produced no change to the heat-up performance of the sample.

Numerous cloth samples were loaded with humidity to levels exceeding 40 grams adsorbed per 100 grams of cloth. Resistance measurements of the samples before and after being loaded with water produced resistance changes up to 50% higher than the virgin cloth samples.

Resistive heating was shown to remove nearly all of these adsorbed species from cloth samples. Greater than 95% of the adsorbed species were removed from the cloth samples via resistive heating regeneration. In the humidity scenarios, the electrical properties of the cloth samples were returned to their virgin state after the water was removed.

Potential Markets

The unique electrical properties of ACC are expected to lead to many exciting new applications. These applications have been divided into the following three market segments.

1. Applications using the electrical conductivity or storage capacity properties of ACC, e.g., capacitors, electrodes, and fuel cells.
2. Applications using electrical heating of ACC without adsorption, e.g., heated clothes, and heated car seats.
3. Applications using electrical heating plus adsorption, e.g., heating/ventilation systems, passenger air systems, and solvent recovery.

References

1. Naamlooze Venootscha Montaan Metaalhandel. United Kingdom Patent Specification, **#207547**, 1924.
2. Sze, S.M., **Semiconductor Devices – Physics and Technology**, Wiley & Sons, 1985.