THE LOW CURRENT CARBON ARC AND THE PROPERTIES OF GRAPHITE NEAR THE SUBLIMATION TEMPERATURE

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Old and new data on the crater radiation from the low current carbon arc have been examined on the basis of two different hypothetical interpretations: (a) the radiation orginates from the crater surface, or (b) the radiation originates from the crater surface and from particles in the adjacent arc stream.

Radiation Originates from Surface

Data from the low current carbon arc[1-3] provides strong evidence that the radiation from the crater can be characterized by a surface temperature close to 3800K. The measured values of spectral radiance are in excellent agreement with those values expected from the Planck radiation formula and the measured values of spectral reflectance (and emittance) over a range of wavelengths from below 0.3 to above 1.7μm. Other data[4,5] agree acceptably with those of References 1-3 regarding the spectral radiance, but they differ greatly in the values for the spectral reflectance and the temperature at the crater surface.

Euler's values of the spectral reflectance[4] are 10 to 15 times too large, but they can be rationalized by taking into account the irradiation-produced increase in temperature of the crater surface. The use of the Null-Lozier[2] and Schurer[3] values of reflectance with values of irradiance[6] appropriate for Euler's experiment leads to the calculation of an irradiation-produced temperature increase of 27K in his experiment and shows that only 5 to 10 percent of this increase in radiance resulted from reflected radiation. An approximate energy balance in Table I for the arc-produced energy fluxes conducted into the electrode and radiated from the crater surface and the assumption that Euler's 120 $W(cm)^{-2}$ irradiation flux absorbed at the crater surface divides in the same ratio as the arc-imposed energy flux leads to calculated temperature increases of 24 and 33K, respectively, for the graphite grade SPK and the lampblack grade L113SP electrodes.

Schurer[3] has shown that Magdeburg's[5] value of crater reflectance is greatly in error because of an incorrect value for the reflectance of the "cold" crater surface.

Schurer[3] found that the crater surface temperatures of ten different grades of high purity electrodes from three manufacturers spread over a range of 50K, indicating that the temperature of the crater surface may depend to a small extent upon the materials and origin of manufacture and, perhaps, upon the conditions of operation of the arc.

The temperature of the crater surface after interrupting the arc (Figure 1) shows initial rapid cooling that fits almost equally well a square root or a linear time dependence over the first 0.05 ms interval for both lampblack and graphite electrode materials. No acceptable interpretation has been found using a linear time dependence for the cooling. The results are satisfactorily interpreted on the basis of radiation from the surface and one-dimensional thermal conduction in a semi-infinite body according to the relation[2]

$$(\Delta T_c)t^{-\frac{1}{2}} = 2(R_0 + F_0)(\pi k c \rho)^{-\frac{1}{2}} \qquad \text{Eq. (1)}$$

where F_0 and R_0 are the heat fluxes at time $t = 0$, respectively, conducted into the body and radiated from the surface; and k, c, and ρ are, respectively, the thermal conductivity, specific heat, and bulk density of the material. The value of thermal conductivity 8.8×10^{-3} $W(cmK)^{-1}$ is calculated from Eq.(1) as shown in Table II. This value of conductivity is 25 to 50 times smaller than that measured for the bulk electrode materials, and it is the same order of magnitude as the values measured by Euler[7] and by Rasor and McClelland[8]. The cooling (extended to longer times) in Figure 1, shows a transition to much slower "square-root-of-time" cooling rates after a temperature decrease and cooling time, respectively, approximately 300K and 100μs for the SPK electrode and 500K and 360μs for the L113SP one. An approximate value for the thickness, ℓ, of the low conductivity layer is obtained from the dimensional relation $\ell^2 = (kt)/c\rho$ giving $\ell = 4.65 \times 10^{-4}$cm and 10.3×10^{-4}cm, respectively, for the SPK and L113SP materials.

The values for the thermal conductivity and the transition time obtained above explain satisfactorily three hitherto puzzling features observed in the intermittent irradiation experiment of Null and Lozier[2]: (a) the instantaneous nature of the temperature changes, (b) the linear dependence of the temperature change upon the value of the irradiance, and (c) the more than two-fold greater temperature change for the lampblack electrode than for the graphite one. In addition, the magnitude of the temperature change is predicted approximately (within 30 to 55 percent).

Radiation Originates from Surface and Particles

A novel interpretation of the radiation from the crater assumes that particles emitted from the crater seriously distort the observations of crater radiance. Our analysis differs from that of Abrahamson[9] in the size and role of the particles. The size of the particles and their fractional surface coverage were determined from the magnitude and spectral characteristics of the reflectance of the "hot" and the "cold" crater surface compared with the known attenuation effects of small particles upon radiation. Our model, consisting of a cloud of graphite particles (radius 0.08μm) and the crater surface at temperatures, respectively, above and below the value

*Retired

3800K, gives a promising explanation of the observed radiance of the graphite-based electrode, but not the lampblack-based one. It may also explain the changes in radiance of the graphite-based electrode caused by irradiation of the crater and those occuring after extinction of the arc, without requiring anomalous reduction of the spectral reflectance and the thermal conductivity near 3800K temperature. However, the irradiation-produced increase of crater radiance is wrongly predicted to be greater for the graphite-based electrode than for the lampblack-based one.

Choice Between the Two Hypotheses

Heat balance and heat transfer modes in the arc stream and at the crater surface have been considered, and they indicate that the spatial distribution of the expended arc power is greatly different with the two interpretations. The "surface" model indicates a larger heat flux conducted from the crater surface to the electrode than the "surface-plus-particles" one, the difference between the values of the conducted heat flux for the two models being expended in the arc space. The "surface" model calls for a large reduction in thermal conductivity when the electrode material approaches the crater surface. The failure of the "surface-plus-particles" model to account for the effect of different electrode materials as contrasted with the near-total success of the "surface" model tips the balance of evidence strongly toward the validity of the latter model.

References

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Table I

Energy Balance at Surface of Electrode

Electrode Crater	Arc Current A	Arc Voltage V	Crater Radius (cm)	Crater Area $(cm)^2$	Current Density $A(cm)^{-2}$	Power* Input $W(cm)^{-2}$	Crater Radiation at Center $W(cm)^{-2}$	Heat Flux** into Electrode $W(cm)^{-2}$
SPK	12.0	62	0.187	0.1099	109.2 (136.5)***	4642 (5800)***	1150	3492 (4650)***
L113SP	9.8	68	0.190	0.1134	86.4 (108.0)***	3672 (4590)***	1150	2522 (3440)***

* Based on average current density x 42.5V (= 38V anode drop + 4.5V electron condensation).
** Based on difference between power input and crater radiation.
*** Estimates of values at center of crater based on current density at center of crater 25 percent greater than the average value.

Table II

Thermal Conductivity at Crater Face Temperature Calculated from Short-Time Cooling Rates

Electrode Grade	Cooling Rate $(\Delta T)t^{-1/2}$ $Ks^{-1/2}$	Heat Capacity $(c\rho)$ $J(cm)^{-3}K^{-1}$	Radiated Flux R_O $W(cm)^{-2}$	Conducted Flux F_O $W(cm)^{-2}$	Sum $(R_O + F_O)$ $W(cm)^{-2}$	Thermal* Conductivity k_z $W(cmK)^{-1}$
SPK	3.48×10^4	4.04	1150	4650	5800	8.75×10^{-3}
L113SP	3.20×10^4	2.98	1150	3440	4590	3.79×10^{-3}

* Thermal conductivity calulated using Eq. 1 with initial cooling rates from Figure 1 and values of conducted flux (F_O) from energy balance (Table I).

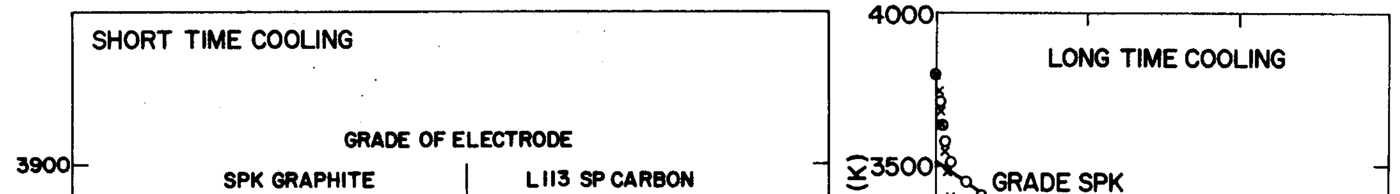

Figure 1. Cooling curves of crater surface temperature after arc extinction for graphite and lampblack electrodes.