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CORRELATION OF EXPERIMENTAL PERFORMANCE DATA FOR A CVD TUNGSTEN-NIOBIUM, PLANAR THERMIONIC CONVERTER

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16. Abstract

Approximate expressions are presented which correlate experimental performance data from a CVD tungsten-niobium, planar thermionic converter. The current-voltage characteristics are given as functions of emitter and collector temperatures and cesium pressure for currents below the knee in the ignited mode. The correlation covers the temperature ranges of 1700 to 1950 K for the emitter, 900 to 1050 K for the collector, and 580 to 645 K for the cesium reservoir.

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SUMMARY

Approximate expressions are presented that correlate experimental performance data from a chemically vapor deposited (CVD) tungsten - niobium, planar thermionic converter. The current-voltage characteristics are given as functions of emitter and collector temperatures and cesium pressure for currents below the knee in the ignited mode. The correlation covers the temperature ranges of 1700 to 1950 K for the emitter, 900 to 1050 K for the collector, and 580 to 645 K for the cesium reservoir.

INTRODUCTION

The designer of a thermionic power system must be able to determine the response of the system to many off design conditions. This entails a knowledge of the performance characteristics of the individual thermionic converters over a wide range of operating conditions. One approach to this end is to use a theoretical synthesis of converter behavior such as SIMCON (ref. 1). The complexity of such a treatment, however, makes its direct use in a system analysis impractical. In general it is necessary to approximate the theory by a number of simple analytical expressions each of which is applicable over a restricted range of operating conditions.

Another approach to the same end is to use data obtained from an experimental performance mapping of an appropriate thermionic converter. A computerized acquisition system (ref. 2) now in use at the Lewis Research Center facilitates collection of the data over a wide range of operating conditions with sufficient density to determine the dependence on all pertinent variables. This performance information is then analyzed to obtain one or more simple correlation expression suitable for use in system calculations. This direct use of experimental data is inherently more accurate than a theoretical treatment and has the added advantage of being able to include behavior for which a theoretical model is lacking.

This report presents correlation expressions for the current, voltage characteristics of a planar thermionic converter with a chemically vapor deposited (CVD) tungsten emitter, a niobium collector, and a 0.25-millimeter interelectrode spacing. They are based on data obtained by E. J. Manista of the Lewis Research Center from the converter described in reference 3. The operating conditions for the data cover the temperature ranges of 1700 to 1950 K for the emitter, 850 to 1050 K for the collector, and 580 to 645 K for the cesium reservoir.

At the present time processing procedures for thermionic converters have not been standardized. In addition critical parameters such as emitter temperature and interelectrode spacing are not always determined accurately. As a result performance data obtained in different laboratories for the same nominal thermionic system are often not in agreement. The present correlation expressions can, nevertheless, be of general use in predicting trends and providing a model for future correlations.

DATA ANALYSIS

It is common practice in the design of thermionic reactor systems to restrict the cesium pressure to values somewhat greater than the optimum value for a given current and fixed emitter and collector temperatures. The operating point then lies on the portion of the current-voltage characteristic below the knee in the ignited mode, where the curve is almost linear. This practice avoids the potential runaway condition in which a local increase in emitter temperature decreases the current density and electron cooling, which further increases the emitter temperature. The present analysis is therefore limited to this approximately linear portion of the ignited mode characteristic.

The data were sorted by the computer and returned in the form of individual current-voltage plots and composite plots with fixed emitter temperature T_E, collector temperature T_C, and varying reservoir temperature T_R. Straight lines were drawn through the points below the knee in the individual plots (fig. 1). These lines were then transferred to the composites and additional lines were drawn through the envelopes (fig. 2). The unignited mode and increasing current points have been deleted from the composites and excluded from the analysis.

The linear portion of the curve has been represented by the form

$$V = A + B(1 - 0.1\,J) \tag{1}$$

where V is in volts and J in amperes per square centimeter. When the intercept A

and slope B are plotted as functions of T_E, T_C, and cesium pressure p (in torr), certain features are readily apparent. The intercept A is linear in T_E and p, and roughly quadratic in T_C (see fig. 3). The slope B is approximately linear in T_E, T_C, and p at high p but departs rapidly from linearity in p for low p (see fig. 4). These considerations lead to the following approximations for A and B.

$$A = a_1 + a_2 t_c + a_3 t_c^2 + a_4 T_E + (a_5 + a_6 t_c)P \tag{2}$$

$$B = b_1 + b_2 t_c + (b_3 + b_4 t_c)t_E + b_5 P + \exp\left\{-\left[b_6 + (b_7 + b_8 t_E)P\right]\right\} \tag{3}$$

with $t_E = 0.001\ T_E - 1.8$, $t_c = 0.001\ T_c - 0.95$, and $P = p - 8$ torr. In addition A and B undergo a fairly abrupt change in their dependence on T_E, T_C, and p for T_E between 1800 and 1850 K. This necessitates the introduction of different values for the a's and b's above and below 1825 K. These values are given in table I.

Equation (1), with A and B replaced by A_e and B_e, is also used to represent the envelope. The approximations for A_e and B_e are

$$A_e = a_1 + a_2 t_c + a_3 t_c^2 + a_4 t_E \tag{4}$$

$$B_e = b_1 + b_2 t_c + b_3 t_E \tag{5}$$

The values for these a's and b's are given in table II.

The approximations in equations (1) to (3) are limited, first by the range of operating conditions covered by the data, and then by the inadequacy of the expressions for part of this range. Emitter and collector temperatures are limited to $1700 \leq T_E \leq 1950$ K and $900 \leq T_C \leq 1050$ K, respectively. Data were also obtained for $T_C \approx 850$ K, but the agreement with the approximation is poor, even though the same general dependence on the variables is observed. The reservoir temperature is limited to $580 < T_R < 635$ K for $T_E < 1825$ K and $13.8\sqrt{T_E} < T_R < 645$ K for $T_E > 1825$ K. The varying lower limit for T_R is due to a departure from linear dependence of A on p at low p for $T_E > 1825$ K.

The linear approximation to the current-voltage characteristic is only valid for currents below the intersection with the envelope and above the unignited mode, that is, for $2 < J < J_e$, where

$$J_e = 10^{\frac{A_e - A + B_e - B}{B_e - B}} \tag{6}$$

For $J_e > 20$ this range is replaced by $2 < J < 20$. These restrictions on the range of operating conditions are summarized in table III.

In figure 5 the analytical expressions (solid lines) are compared with the straight lines drawn through the experimental data (shown as a series of crosses) for T_E's of 1750 and 1900 K. Note that the crosses are drawn at equal increments in J and do not represent the actual data points. In general the agreement is better than ±25 millivolts except for $T_C \approx 1000$ K and $T_E < 1825$ K (fig. 5(c)). Here, the discrepancy grows to 40 millivolts at the highest pressures.

CONCLUDING REMARKS

Approximate correlating expressions have been obtained for the current-voltage characteristics of a planar thermionic converter with a CVD tungsten emitter, niobium collector, and an 0.25-millimeter interelectrode spacing.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 2, 1972,
503-25.

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3. Smith, Arthur L.: Computer-Acquired Performance Data From a Chemically Vapor-Deposited-Tungsten, Niobium Planar Diode. NASA TM X-2373, 1971.

TABLE I. - APPROXIMATION TO CURRENT-VOLTAGE CHARACTERISTICS

$$V = A + B(1 - 0.1\ J)$$

$$A = a_1 + a_2 t_c + a_3 t_c^2 + a_4 t_E + (a_5 + a_6 t_c)P$$

$$B = b_1 + b_2 t_c + (b_3 + b_4 t_c)t_E + b_5 P + \exp\left\{-\left[b_6 + (b_7 + b_8 t_E)P\right]\right\}$$

$$t_E = 0.001\ T_E - 1.8,\quad t_c = 0.001\ T_C - 0.95,\quad P = p - 8\ \text{torr}$$

Emitter temperature, T_E, K	Coefficients					
	a_1	a_2	a_3	a_4	a_5	a_6
<1825	0.370	0.63	-6.3	1.84	-0.0314	0.102
>1825	.400	.71	-7.1	1.78	-.0354	.098

Emitter temperature, T_E, K	Coefficients							
	b_1	b_2	b_3	b_4	b_5	a_6	b_7	b_8
<1825	0.184	-0.48	0.25	-0.58	0.013	6.39	0.60	0
>1825	.184	-.46	.26	-.57	.014	6.80	.53	5.4

TABLE II. - APPROXIMATION TO CURRENT-VOLTAGE ENVELOPE

$$V = A_e + B_e(1 - 0.1\,J)$$

$$A_e = a_1 + a_2 t_c + a_3 t_c^2 + a_4 t_E$$

$$B_e = b_1 + b_2 t_c + b_3 t_E$$

$$t_E = 0.001\,T_E - 1.8$$

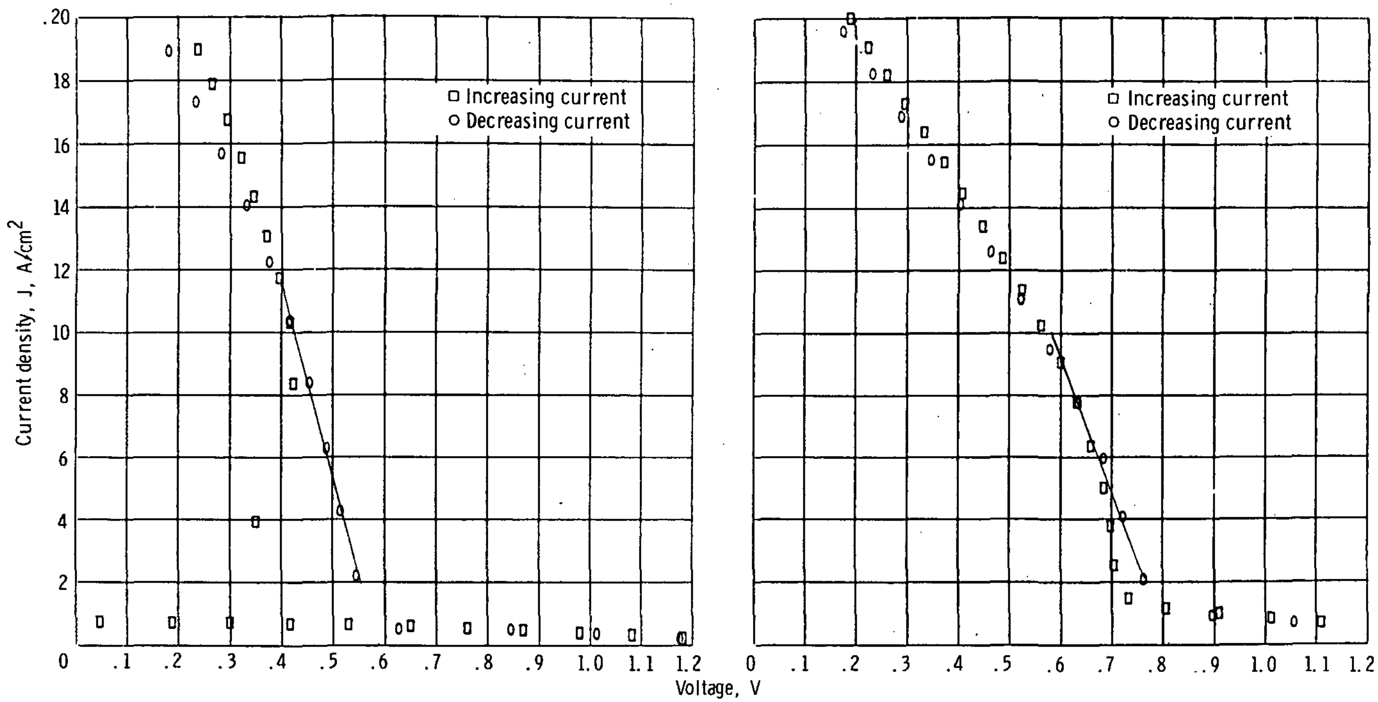
$$t_C = 0.001\,T_C - 0.95$$

Emitter temperature, T_E, K	Coefficients						
	a_1	a_2	a_3	a_4	b_1	b_2	b_3
<1825	0.523	0.160	-8.0	1.68	0.230	-0.56	0.68
>1825	.523	.402	-6.7	1.11	.311	-1.08	.79

TABLE III. - RESTRICTIONS ON OPERATING CONDITIONS

Current[a]	$2 < J < J_e$ for $J_e < 20$ $2 < J < 20$ for $J_e > 20$
Emitter	$1700 \leq T_E \leq 1950$ K
Collector	$900 \leq T_C \leq 1050$ K
Reservoir	$580 < T_R < 635$ K for $T_E < 1825$ K $13.8\sqrt{T_E} < T_R < 645$ K for $T_E > 1825$ K

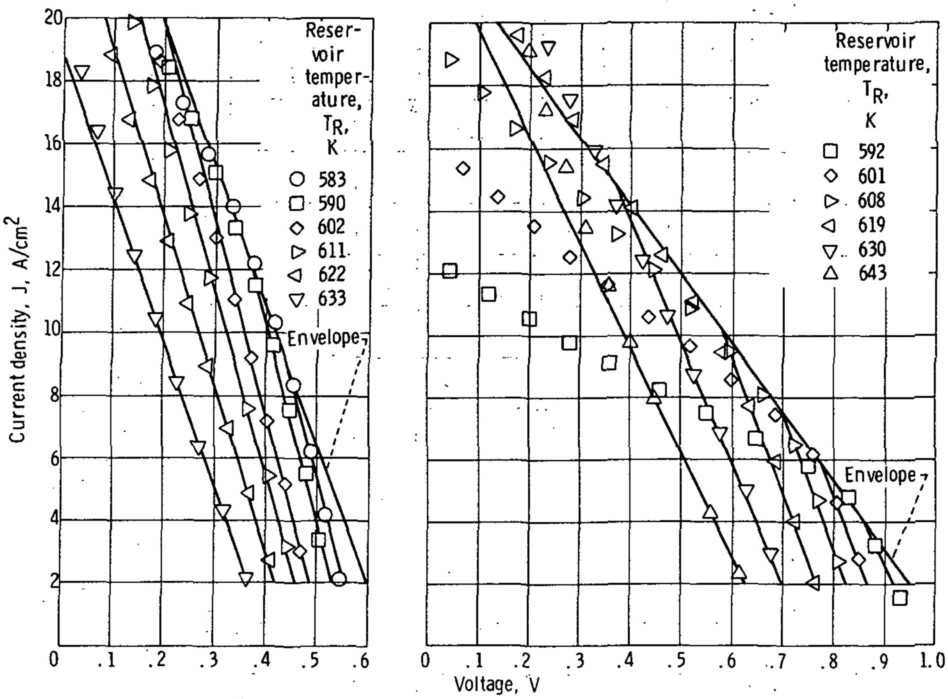
[a]$J_e = 10(A_e - A + B_e - B)/(B_e - B)$.



(a) Emitter temperature, 1750 K; collector temperature, 904 K; reservoir temperature, 583 K.

(b) Emitter temperature, 1900 K; collector temperature, 897 K; reservoir temperature, 619 K.

Figure 1. - Current-voltage plot.



(a) Emitter temperature, 1750 K.

(b) Emitter temperature, 1900 K.

Figure 2. - Composite current-voltage plot. Collector temperature, 900 K; unignited mode and increasing current points deleted.

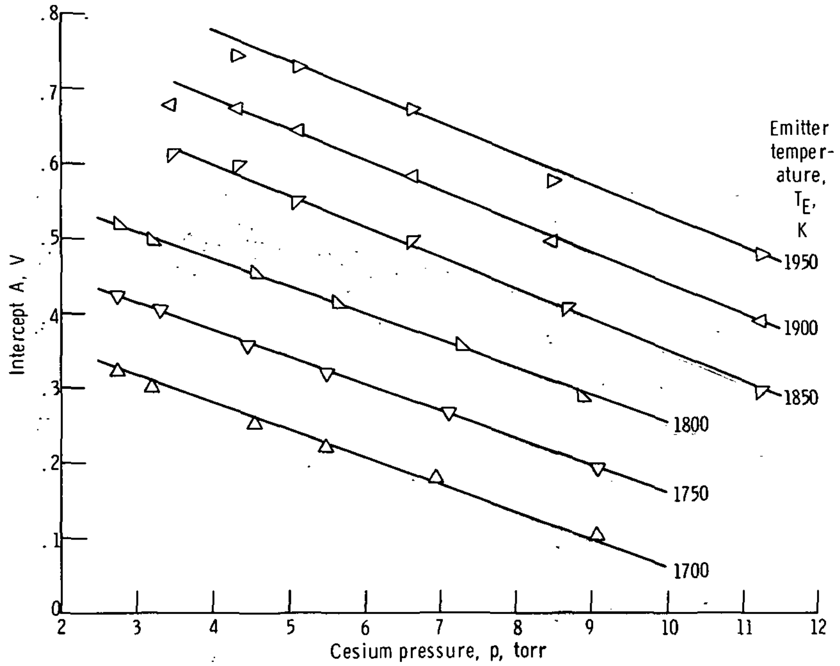


Figure 3. - Intercept as function of pressure p. Collector temperature, 900 K.

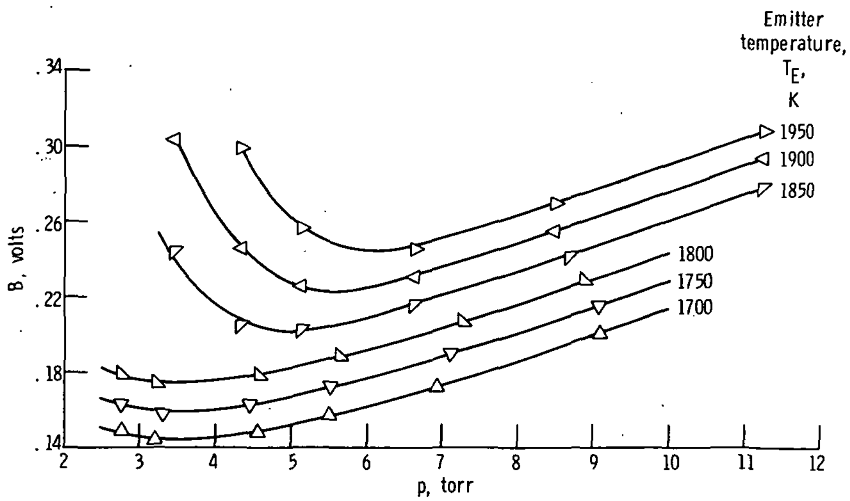
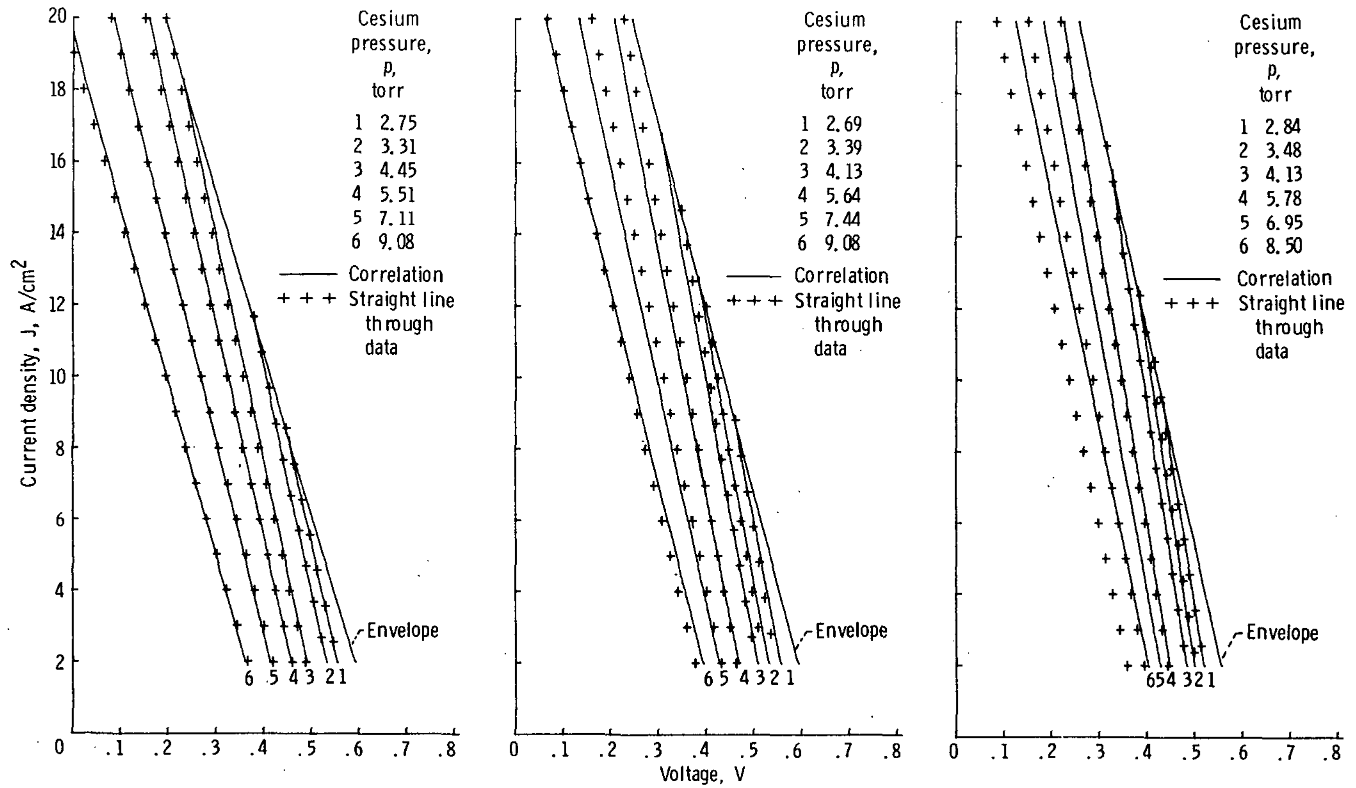


Figure 4. - Slope B as function of pressure p. Collector temperature, 900 K.

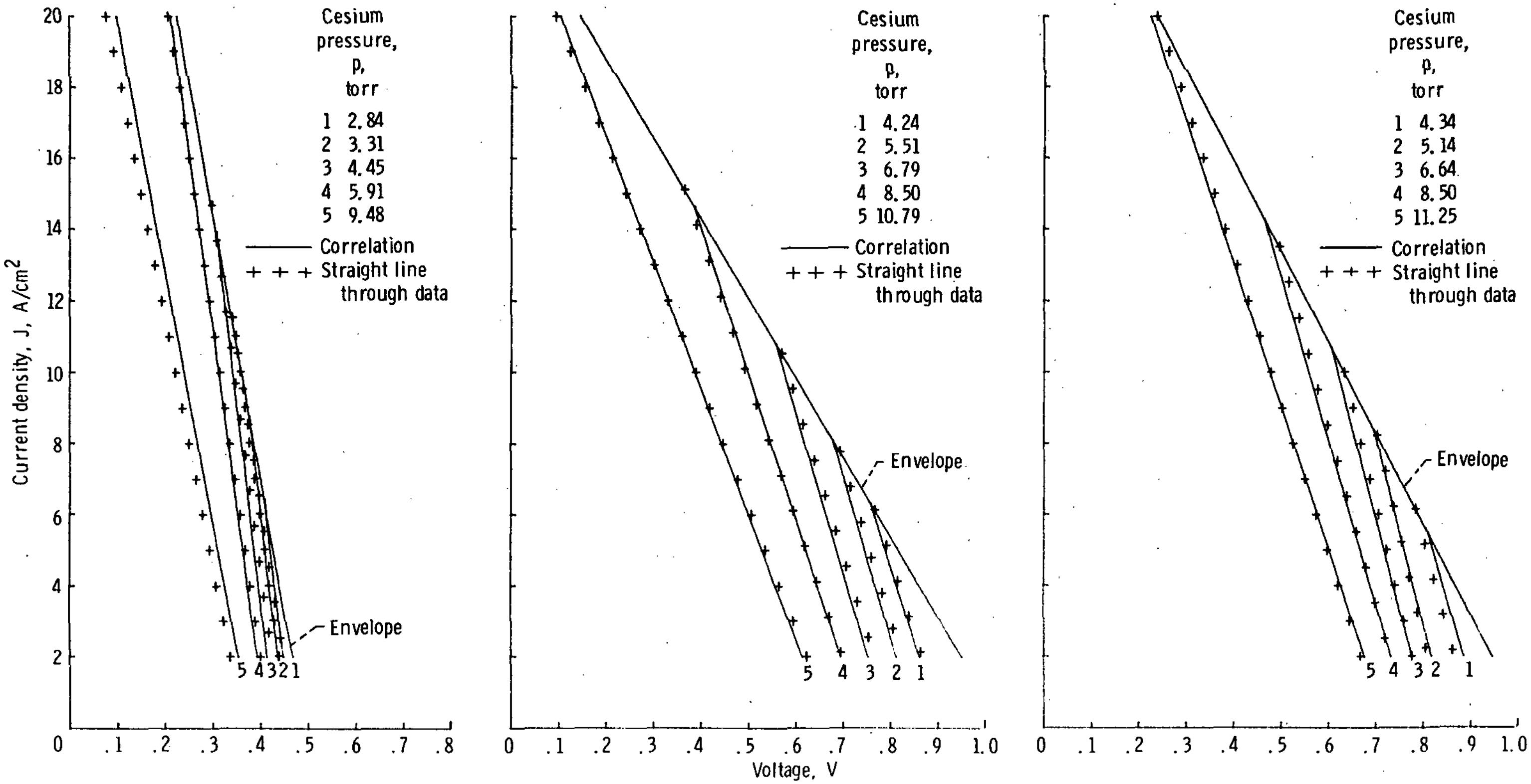


(a) Emitter temperature, 1750 K; collector temperature, 905 K.

(b) Emitter temperature, 1750 K; collector temperature, 955 K.

(c) Emitter temperature, 1750 K; collector temperature, 1004 K.

Figure 5. - Comparison of correlation with data.

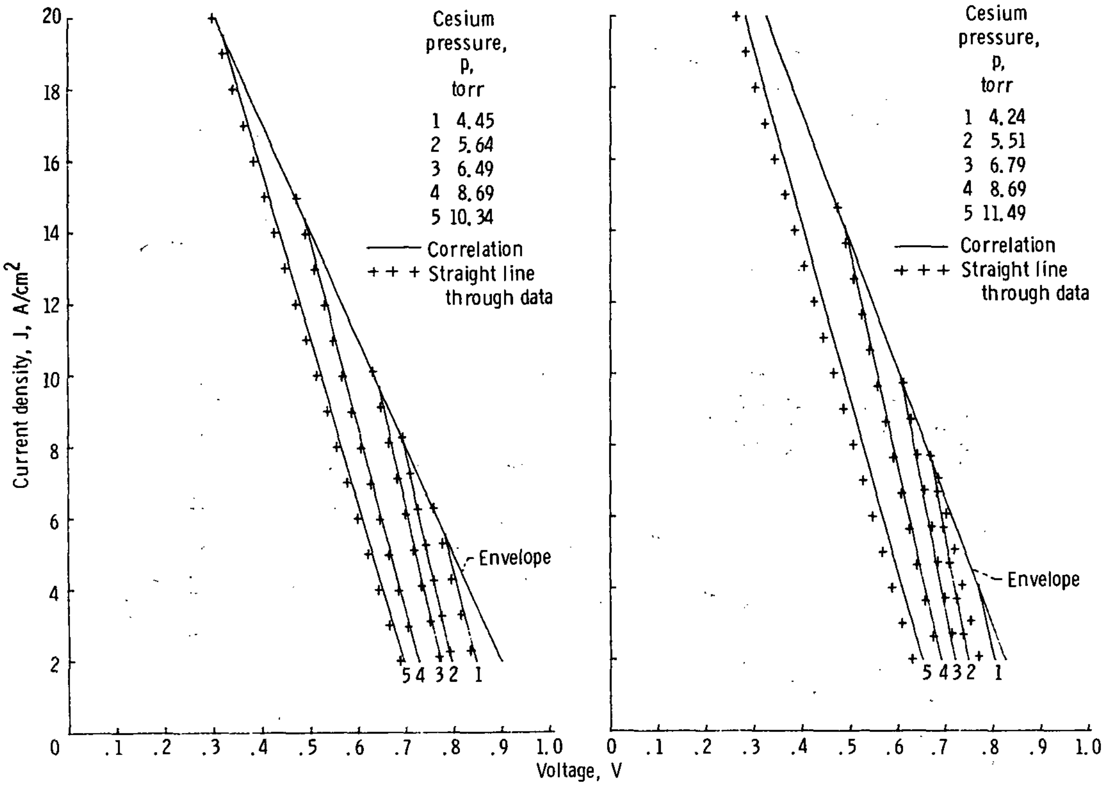


(d) Emitter temperature, 1750 K; collector temperature, 1059 K.

(e) Emitter temperature, 1900 K; collector temperature, 897 K.

(f) Emitter temperature, 1900 K; collector temperature, 948 K.

Figure 5. - Continued.



(g) Emitter temperature, 1900 K; collector temperature, 1005 K.

(h) Emitter temperature, 1900 K; collector temperature, 1053 K.

Figure 5. - Concluded.

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