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PARAMETERS AFFECTING ELECTROSTATIC COOLING

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16. ABSTRACT

A high voltage electrostatic field enhances the rate of normal convective cooling. This cooling rate is a function of starting temperature and voltage applied, and an inverse function of atmospheric pressure or the heat capacity of the surrounding media. It appears that the cooling rate is also a function of current flow; however, additional work is needed to separate other variables from the effect of current flow.

The maximum increase in heat loss over the normal convective cooling was approximately 0.167°C/sec (0.3°F/sec) at 316°C (600°F) and 20 000 V. From the data taken it is assumed that the added rate of cooling would be increased with higher temperatures and higher voltages.

It appears that a high voltage field disrupts the molecular layer of air surrounding a hot body and increases the rate of convective cooling.

Future tests are planned to further characterize this phenomenon and to determine applications for electrostatic cooling.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Technical Memorandum X-73350

PARAMETERS AFFECTING ELECTROSTATIC COOLING

INTRODUCTION

It has been established that a high voltage electrostatic field tends to increase the rate of heat loss from a hot body within the field. The present work was done to determine the effects of various parameters such as voltage, probe configuration, probe spacing, atmospheric pressure, and surrounding media on electrostatic cooling.

Since thermal control, particularly in reentry bodies, is often a problem, it is possible that electrostatic cooling may be a useful method of increasing the rate of heat rejection from hot surfaces. Although a high voltage field is required for electrostatic cooling, little current flow is required; thus the total power consumption is minimal.

ELECTROSTATIC COOLING TESTS

To establish the effect of various parameters on electrostatic cooling rate, a test program was set up so that voltage, probe spacing, probe configuration, atmospheric pressure, and atmospheric media could be controlled.

All tests were made in a vacuum bell jar to limit the effects, as much as possible, of outside air currents on the measured cooling rates. The test setup is shown schematically in Figure 1. A high voltage variable power supply located outside the bell jar was connected to a probe that was spaced a selected distance from the aluminum thermal plate. The plate was grounded to the power supply, and was provided with three thermocouples located at the center of the plate and 6.35 cm (2.5 in.) above and below the center. An optical pyrometer was also used as a check on the thermocouple readings. Plate heating was provided by a high intensity heat lamp positioned behind the plate.

Effect of Voltage

The first test was made to determine the effect of various applied voltages on the cooling rate of a 210-gram aluminum plate heated to approximately 316°C (600°F). A point probe spaced approximately 3.97 cm (1.56 in.) from the plate was used. The test was made in 1.05 kg/cm^2 (15 psi) air with the probe voltage applied as soon as the power to the heat lamp was shut off. The results of this test are shown in Figure 2. These data indicate that cooling rate is a direct function of applied voltage.

Effect of Atmospheric Pressure and Media

Since atmospheric pressure may affect the cooling rate, several tests were made to determine the role played by pressure in electrostatic cooling. Figure 3 shows the results of tests in reduced atmospheric pressure using the same test configuration previously described and with 15 kV applied to the probe. As expected the rate of cooling is also a direct function of atmospheric pressure. It was also expected that the heat capacity of the surrounding media would affect the cooling rate; therefore, the cooling rates were compared in helium, which has a relatively high heat capacity, and in air. Results of these tests are shown in Figure 4. When using 20 kV on the probe it was noted that the original cooling rate in helium was very rapid, but by the end of 600 sec the cooling rate in air was approximately the same. This effect may be explained by a faster temperature rise in the chamber for the helium test since the chamber is a closed system. This assumption is borne out by plotting the delta temperature variation from 0 kV in air for both helium and air at 20 kV as shown in Figure 5. This plot shows a fairly steady logarithmic curve for air, while the cooling rate in helium tends to slow dramatically as the chamber temperature increases.

Effect of Probe Spacing

The effect of probe spacing was measured by moving the probe back to a distance of 7.94 cm (3.125 in.) from the thermal plate. Results of this test are shown in Figure 6. This test indicated that the spacing of the probe had little effect on the cool-down rate.

Effect of Probe Configuration and Current Flow

The final variable to be examined in this test series was probe configuration. A three-point probe and a flat-plate probe were compared with a single-point probe. Results of these tests are shown in Figure 7. The flat-plate probe proved to be the least effective, and the three-point probe was the most effective. It was also interesting to note that the three-point probe drew approximately twice as much current as the one-point probe; therefore results from several tests were plotted versus current draw. These results are shown in Figure 8. These tests appear to indicate that the electrostatic cooling rate is also a function of current flow.

Analysis

Using the experimentally developed curves, a series of equations was developed relating electrostatic cooling to time at two voltages and at two probe distances in 1.05 kg/cm^2 (15 psi) air. These equations are shown below with t = time in seconds and T = temperature in °F:

<u>0 kV</u>

$$T = 609 - 1.47\,t + 2.14 \times 10^{-3}\,t^2 - 1.27 \times 10^{-6}\,t^3 \quad . \qquad (1)$$

10 kV, 3.97-cm (1.56-in.) Spacing

$$T = 599 - 1.66\ t + 2.74 \times 10^{-3}\ t^2 - 1.79 \times 10^{-6}\ t^3 \quad . \tag{2}$$

20 kV, 3.97-cm (1.56-in.) Spacing

$$T = 598 - 1.83\ t + 3.13 \times 10^{-3}\ t^2 - 2.07 \times 10^{-6}\ t^3 \quad . \tag{3}$$

10 kV, 7.94-cm (3.125-in.) Spacing

$$T = 599 - 1.63\ t + 2.58 \times 10^{-3}\ t^2 - 2.16 \times 10^{-6}\ t^3 \quad . \tag{4}$$

20 kV, 7.94-cm (3.125-in.) Spacing

$$T = 606 - 1.92\ t + 3.29 \times 10^{-3}\ t^2 - 2.16 \times 10^{-6}\ t^3 \quad . \tag{5}$$

To make a direct comparison of the effect of the voltage and spacing variables, equation (1) was subtracted from equations (2), (3), (4), and (5) to give the following equations:

20 kV, 7.94-cm (3.125-in.) Spacing

$$\Delta T = 0.45\ t + 0.99 \times 10^{-3}\ t^2 - 0.80 \times 10^{-6}\ t^3 \quad . \tag{6}$$

20 kV, 3.97-cm (1.56-in.) Spacing

$$\Delta T = -0.36\ t + 0.99 \times 10^{-3}\ t^2 - 0.80 \times 10^{-6}\ t^3 \quad . \tag{7}$$

10 kV, 7.94-cm (3.125-in.) Spacing

$$\Delta T = -0.16\ t + 0.44 \times 10^{-3}\ t^2 - 0.34 \times 10^{-6}\ t^3 \quad . \tag{8}$$

10 kV, 3.97-cm (1.56-in.) Spacing

$$\Delta T - 0.19\ t + 0.60 \times 10^{-3}\ t^2 - 0.52 \times 10^{-6}\ t^3 \quad . \tag{9}$$

Since t at each time is the same for each equation and the powers of 10 are equivalent, the coefficients for each power are the controlling factors; therefore, the coefficients of each factor were added together to provide a variability T′ factor by which each set of variables can be compared:

20 kV, 7.94-cm (3.125-in.) Spacing: $T' = -0.19$

20 kV, 3.97-cm (1.56-in.) Spacing: $T' = -0.17$

10 kV, 7.94-cm (3.125-in.) Spacing: $T' = -0.06$

10 kV, 3.97-cm (1.56-in.) Spacing: $T' = -0.11$

If the equations for various voltages at 3.97-cm (1.56-in.) and 7.94-cm (3.125-in.) spacing are differentiated and dT/dt is plotted against voltage, we have the plots shown in Figure 9. These data indicate that at 300 sec or at approximately 37.77°C (100°F) to 93.32°C (200°F) above room temperature, electrostatic cooling is not effective. This fact is further illustrated by Figure 10, where dT/dt is plotted against time for 20 kV and 3.97-cm (1.56-in.) and 7.94-cm (3.125-in.) probe spacing. Attempts were made to electrostatically cool below room temperature and to electrostatically cool in hard vacuum. Neither of these attempts was successful; therefore, it must be concluded that the electrostatic field enhances the ability of the surrounding media to remove heat from the surface. A further examination of Figure 9 indicates that a 20-kV electric field increases the rate of heat loss approximately 0.167°C/sec (0.3°F/sec) during the first 20 sec from 316°C (600°F) as compared with no voltage. This added cooling is then reduced to zero as the hot body approaches the temperature of the surrounding media.

CONCLUSIONS

The evaluation of various parameters associated with cooling by a high voltage electrostatic field demonstrates the following:

1. The cooling rate of a hot body is increased over normal convective cooling by the presence of a high voltage electrostatic field.

2. The increase in cooling rate is a function of the delta temperature between the hot body and the surrounding media, is a function of the voltage between the probe and the hot body, and is an inverse function of the heat capacity of the surrounding media.

3. It also appears that current flow may be a contributing factor to the rate of heat loss.

4. From these tests it appears that electrostatic cooling operates by the disruption of the gas molecular layer surrounding the hot body and is not effective in a vacuum or when the temperature of the hot body approaches that of the surrounding media.

FUTURE PLANS

Additional tests are planned to further characterize the parameters affecting electrostatic cooling and to determine practical means of applying this phenomenon to the solution of thermal control problems encountered in the space program.

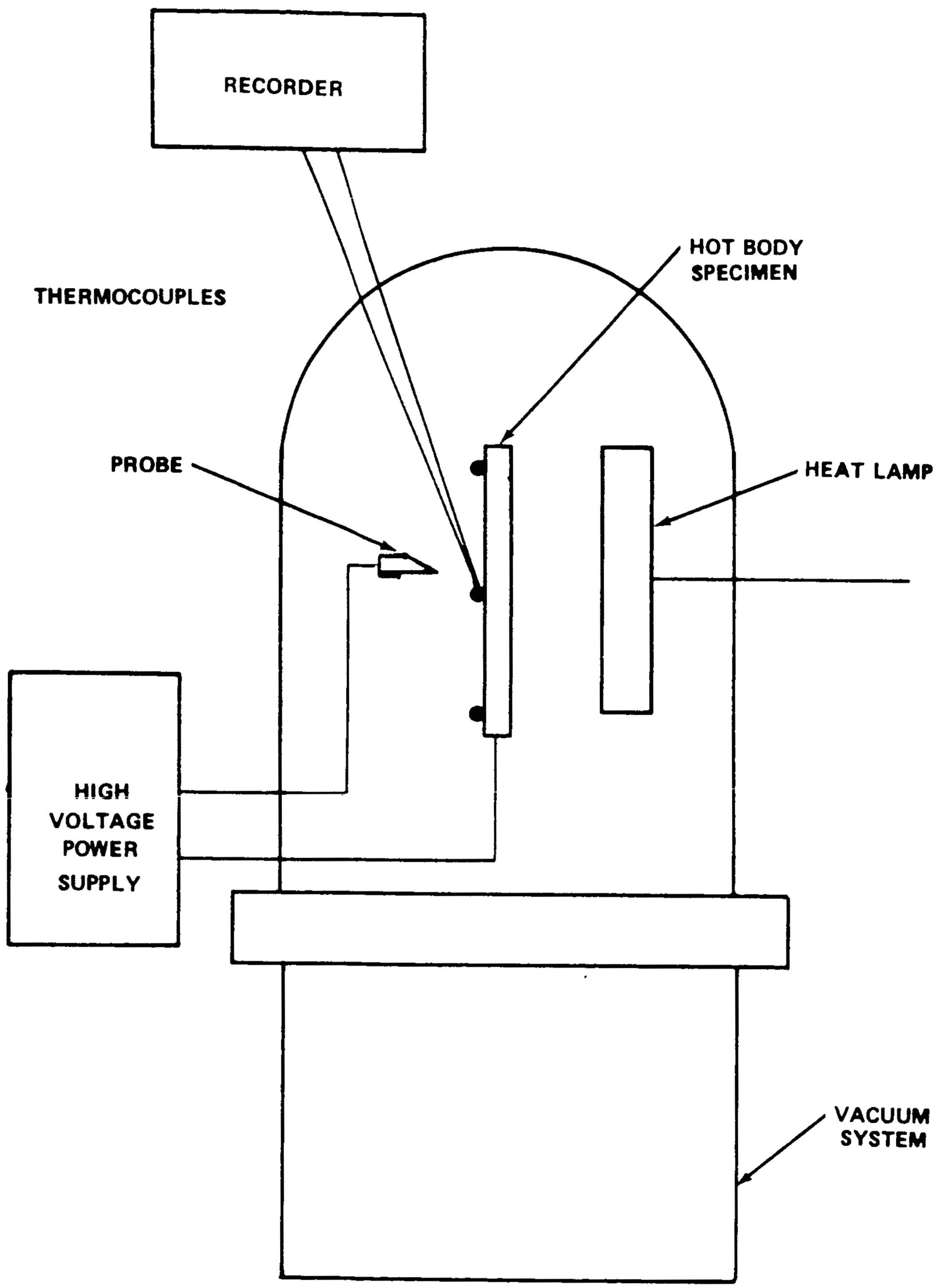

Figure 1. Test configuration.

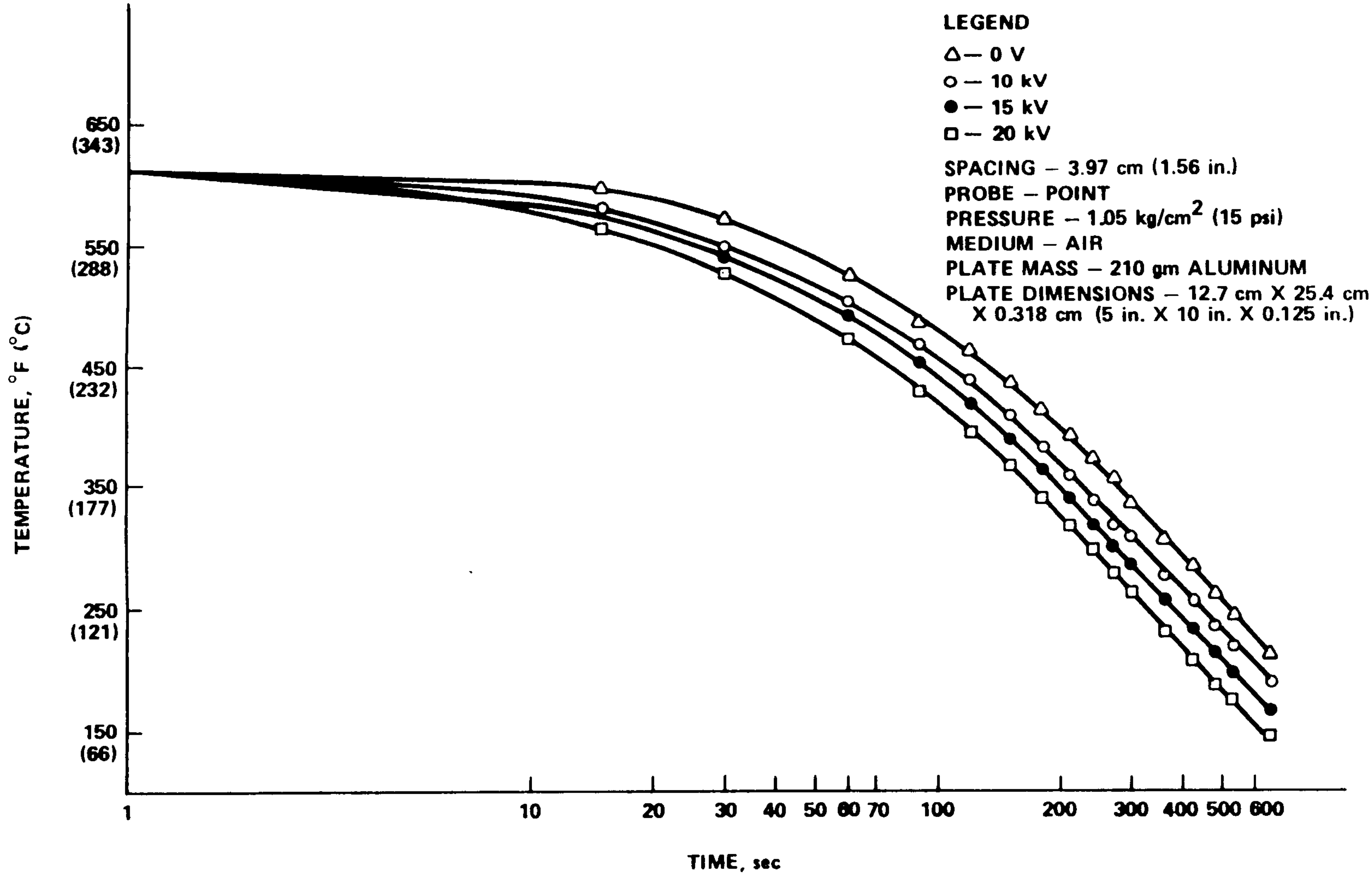

Figure 2. Effect of voltage on cooling rate.

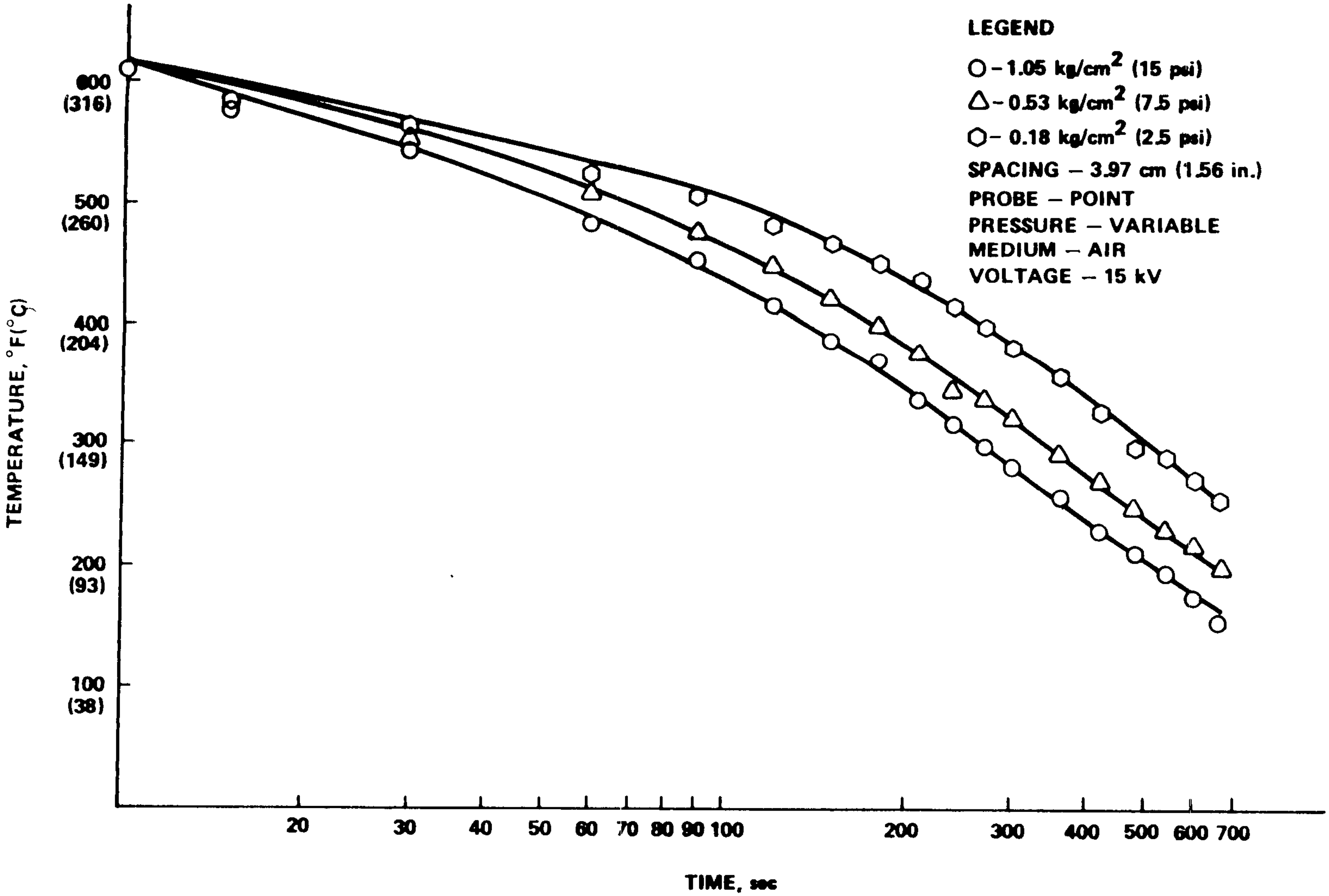

Figure 3. Effect of pressure on cooling rate.

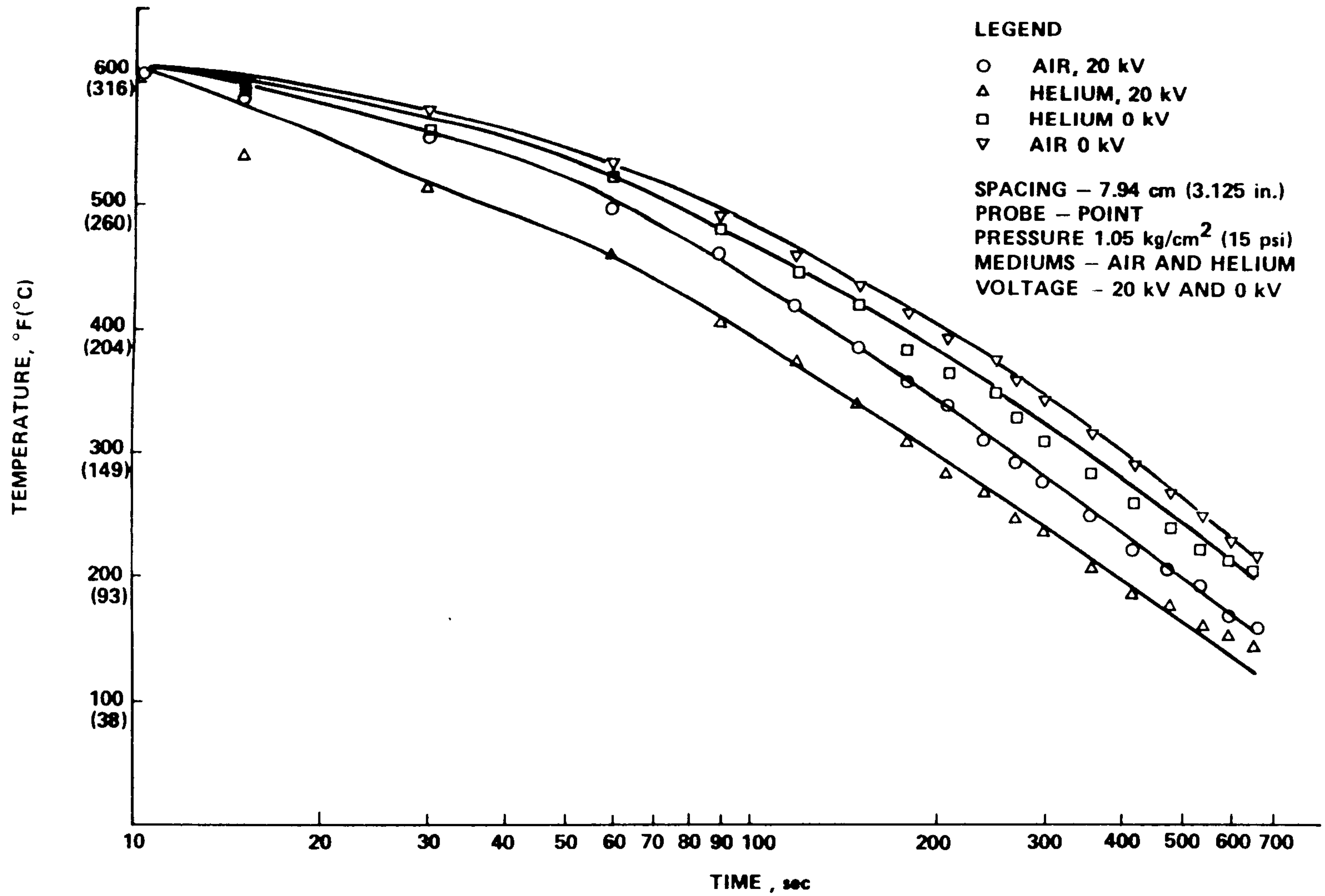

Figure 4. Effect of medium on cooling rate.

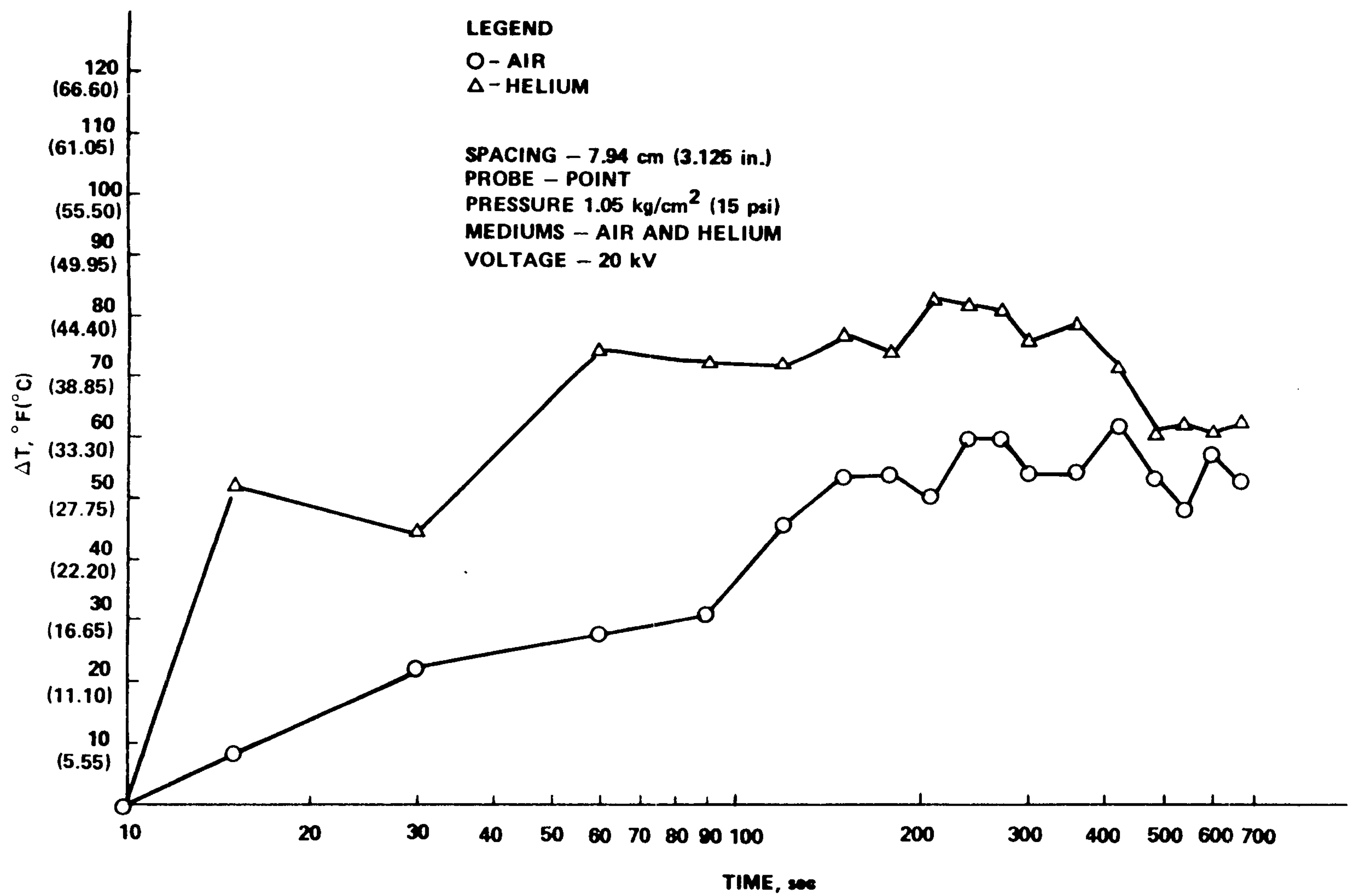

Figure 5. Effect of medium on change in cooling rate versus time at zero voltage.

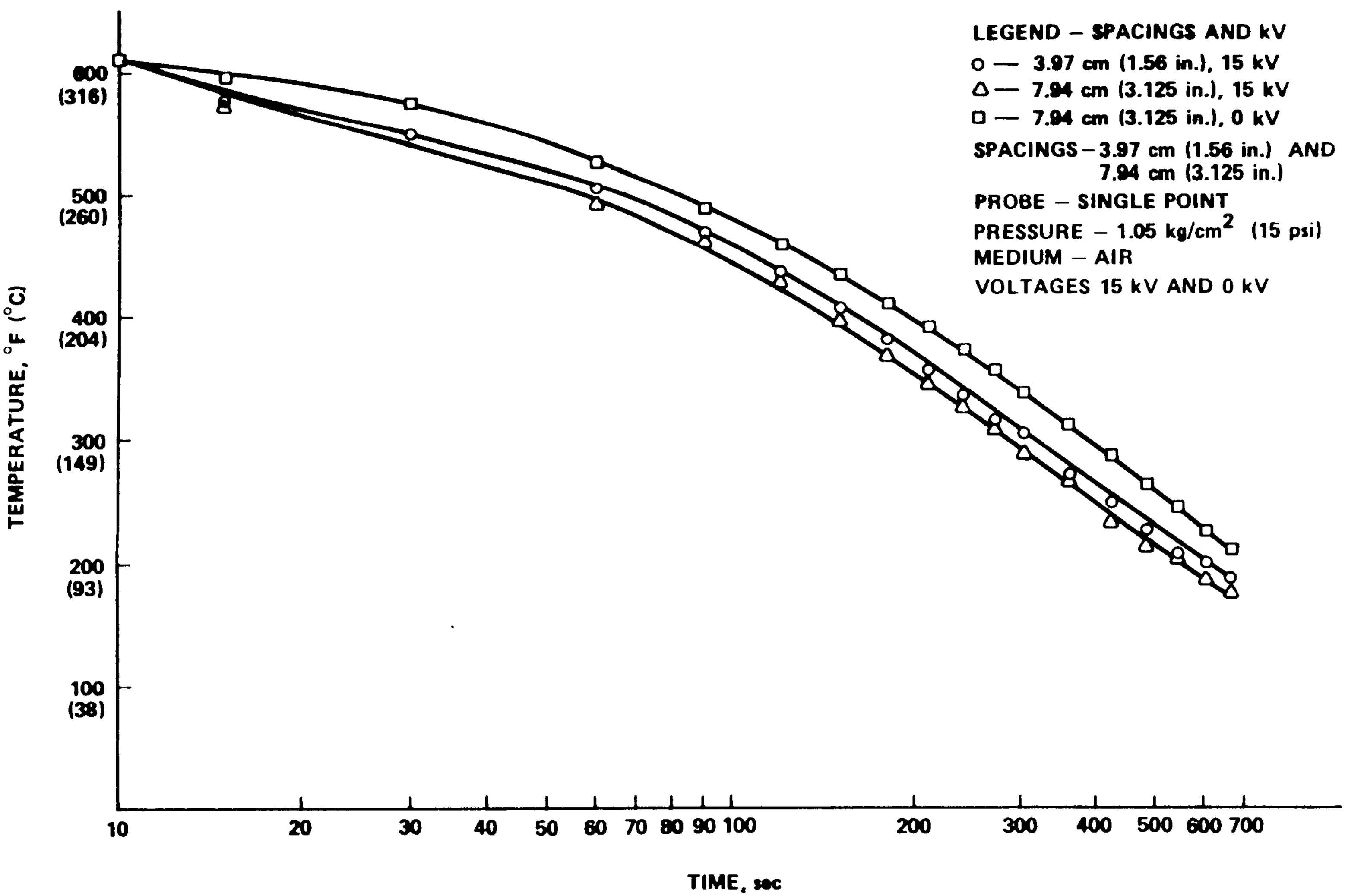

Figure 6. Effect of probe spacing on cooling rate.

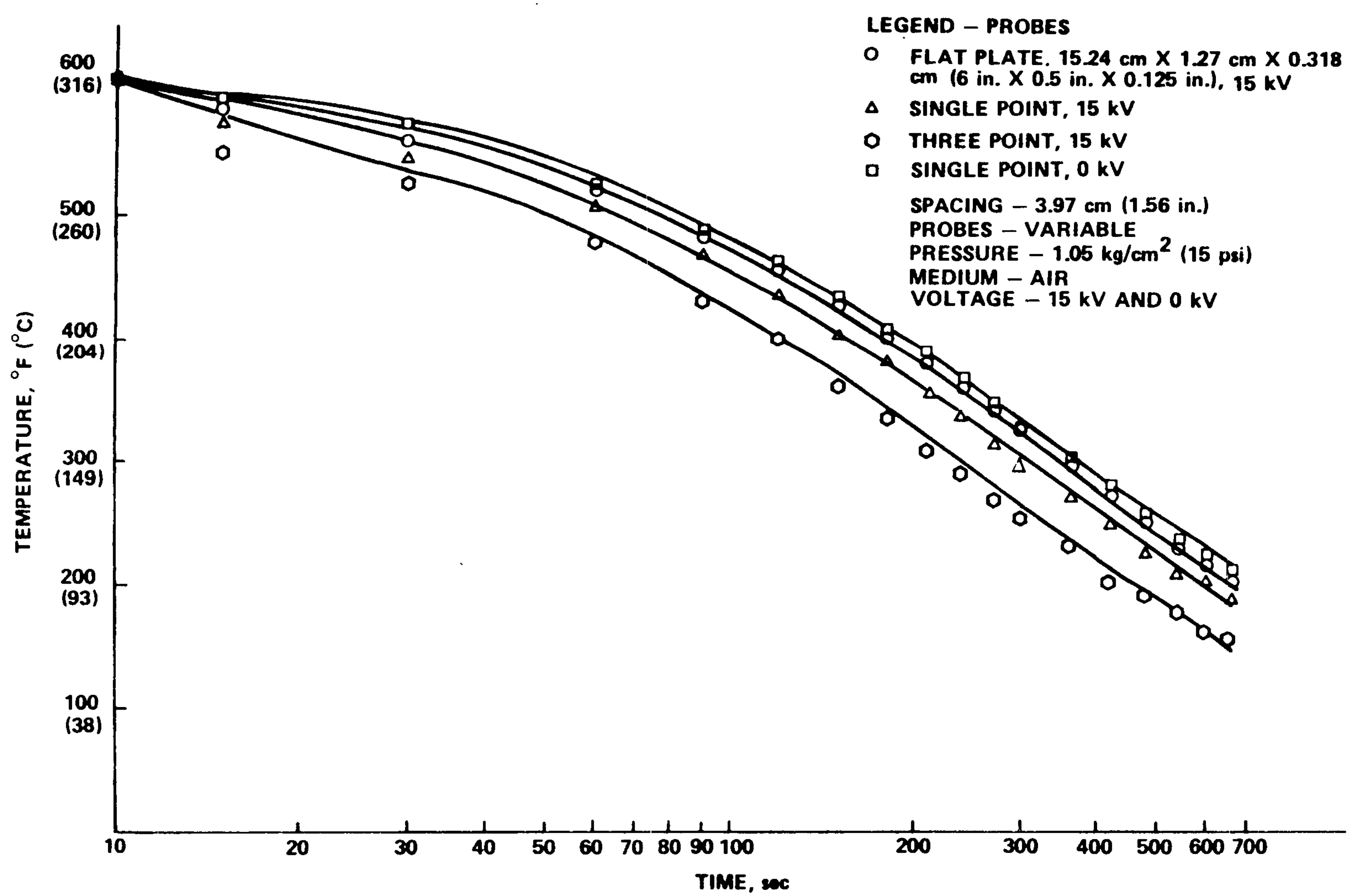

Figure 7. Effect of probe configuration on cooling rate.

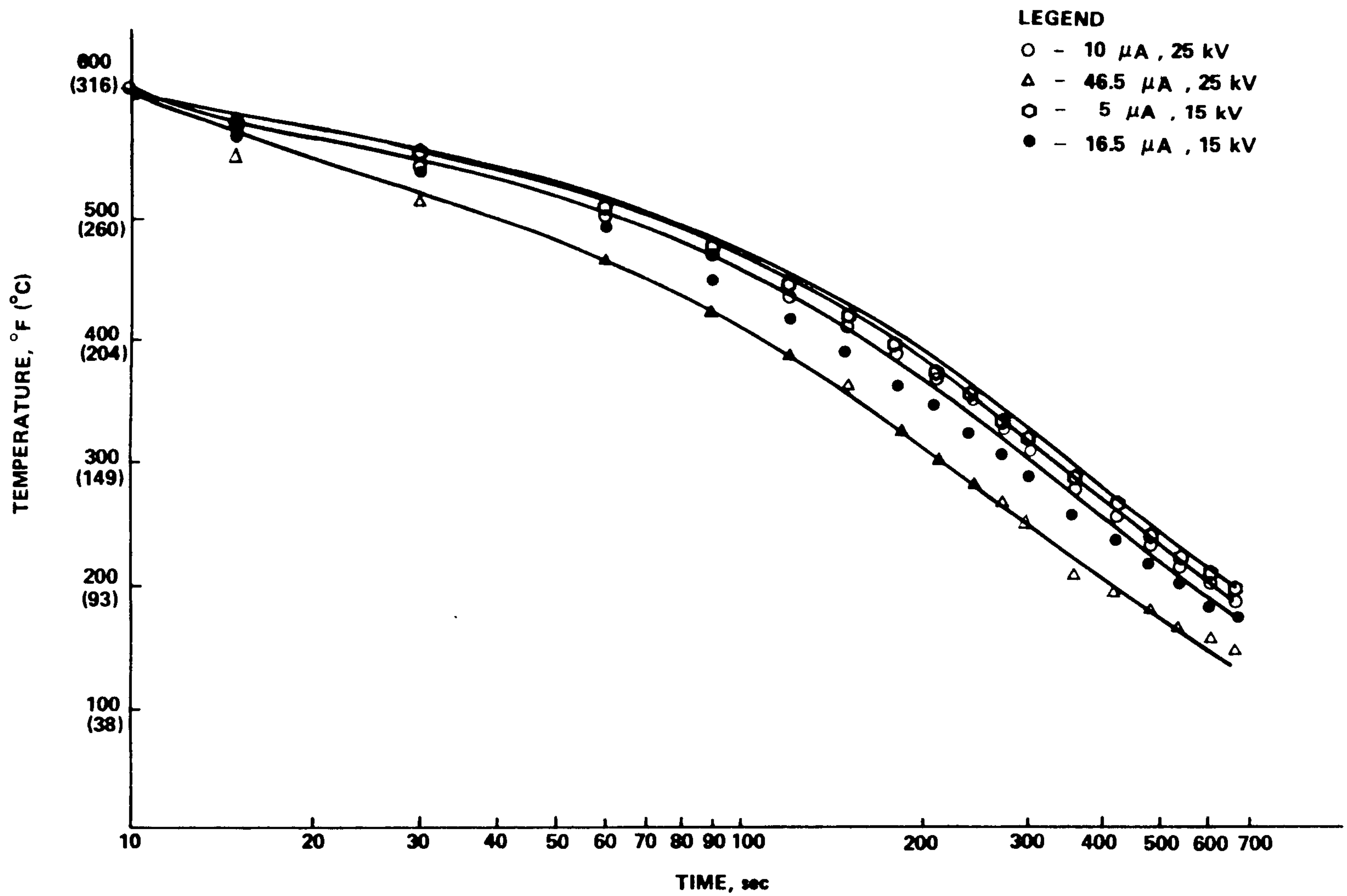

Figure 8. Effect of current flow on cooling rate.

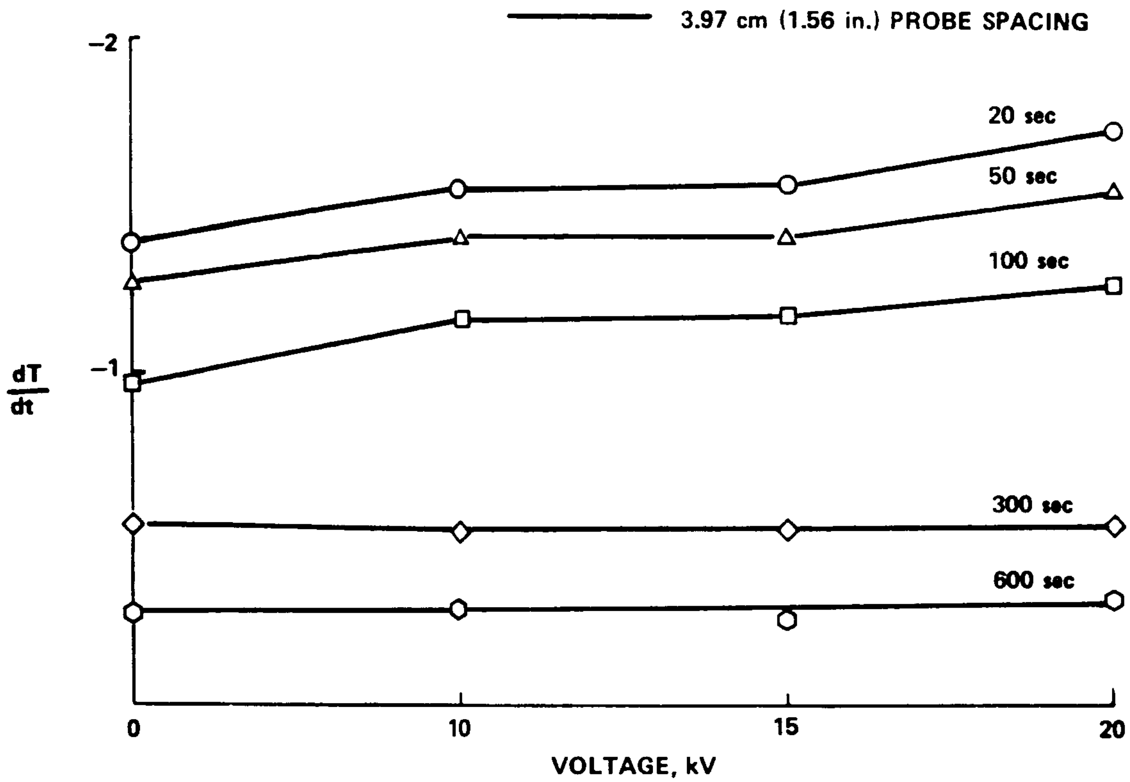

Figure 9. Change in temperature with respect to time versus voltage at 20, 50, 100, 300, and 600 sec.

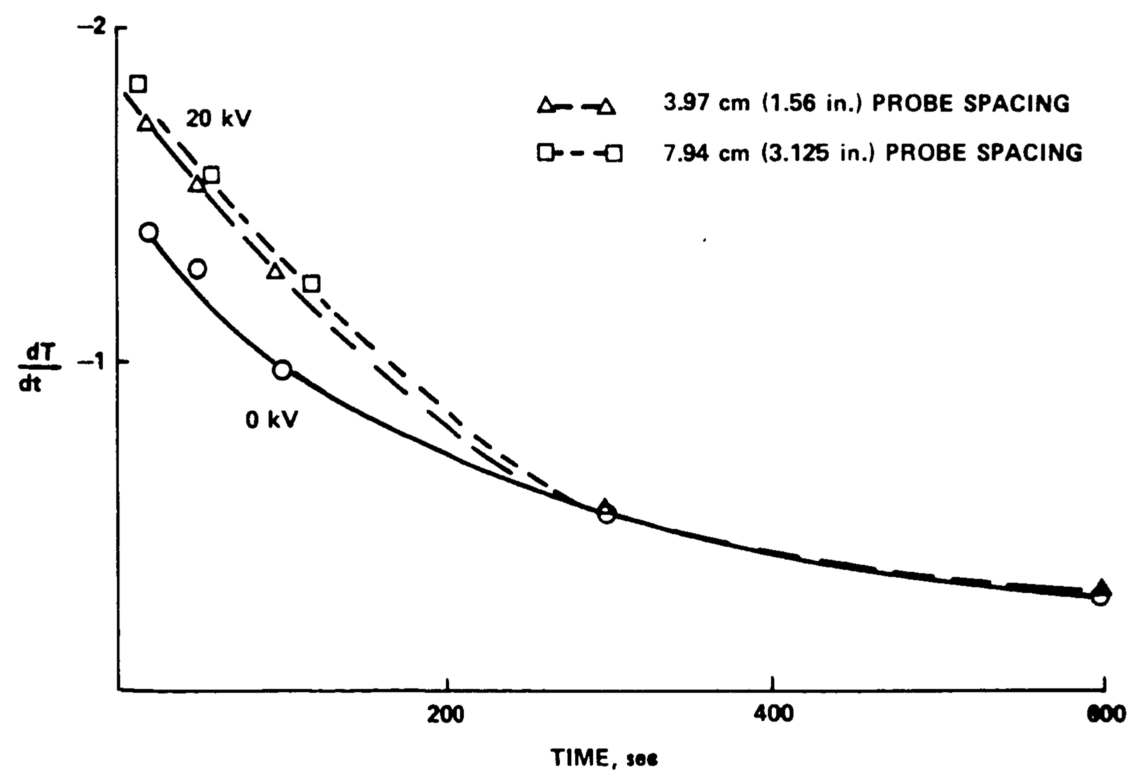

Figure 10. Change in temperature with respect to time versus time at 0 and 20 kV.