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CALCULATION OF MAXIMUM
RATE OF DIELECTRIC HEATING
OF EXPLOSIVES

by

ALEXANDER MACKENZIE

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H. J. MATSUGUMA
Chief, Explosives
Research Section

Approved by:

L. H. ERIKSEN
Chief, Explosives and
Propellants Laboratory

Feltman Research Laboratories
Picatinny Arsenal
Dover, N. J.

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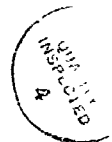
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In many experiments done with explosives it is necessary to rapidly heat the explosive. The common technique is to introduce the heat by conduction. These experiments are difficult to treat theoretically because it's not at all clear what the temperature is at a small fraction of a second after the start of heat conduction. As a result interest is found in the rapid body heating of explosives where large thermal gradients can be avoided. The most obvious applicable technique is to use dielectric heating.

Before proceeding one would like to know what heating rates can be achieved placing no limit on the available power. In calculating this quantity one can argue in terms of a complex dielectric constant or an ideal condenser shunted by a resistor. Although the two approaches are essentially the same, the latter was used since it is more acceptable in the electronics laboratory.

For the resistor and lossless condenser in parallel the complex impedance is

$$1) \quad Z^* = \frac{RX_c^2 - R2x_c5}{R2 + x_0^2}$$

and R is the ratio of applied voltage to the current component in phase with the voltage.

This gives a phase angle γ

$$2) \quad \tan \gamma = -\frac{R}{X_c} , \quad \text{i.e. current leading}$$

For the average power P

$$3) \quad P = V^2/R$$

or

$$4) \quad P = \frac{V^2}{X_c \tan \gamma}$$

Using MKS units and assuming a uniform field in the parallel plate condenser, the capacitive reactance is

$$5) \quad X_c = \frac{d}{2 \pi \varepsilon_0 R A \mathcal{J}}$$

where d is plate separation, A plate area, R relative dielectric constant, $\mathcal{J}$ frequency and   electric permitivity.

Using the maximum voltage that can be applied across the explosive

and introducing dielectric strength E.

$$6) \quad V_{max} = Ed = \sqrt{2} \; V$$

Combining equations 4, 5 and 6

$$7) \quad P = \frac{\pi \, \varepsilon_0 k E^2 \, f \, \mathcal{V}}{Tan \; \gamma}$$

where $\mathcal{V}$ is the volume Ad in meters^3.

Making use of the heat equation expressed in Joules

$$8) \quad H = 10^6 \, \mathcal{S} \, \gamma \, S \Delta T \, J$$

density $\mathcal{S}$ in gm/cm^3, specific heat s in cal/gm$^\circ$C, temperature ΔT in $\circ$C and J Joules/cal.

Equating P_t energy, from eq. 7 to eq. 8 and solving for the rate of change of temperature

$$9) \quad \frac{\Delta T}{} = \frac{\pi \, \varepsilon_0 \, k f}{10^6 \, J \, \mathcal{S} \, S} \; \frac{E^2}{Tan \; \gamma}$$

$$10) \quad \frac{\Delta T}{t} = 6.6 \times 10^{-18} \; \frac{k \, f}{\mathcal{S} \, S} \; \frac{E^2}{Tan \; \gamma}$$

In dielectric heating the loss angle -θ- is used where -θ- is the compliment of γ . Then

$$11) \quad \frac{\Delta T}{t} = 6.6 \times 10^{-18} \; \frac{k \, f}{\mathcal{S} \, S} \; E^2 \; Tan \; -\theta--$$

In condenser work where low losses are realized the dissipation factor, Tan -θ-, is replaced by the power factor.

Some electrical measurements have been made on Comp B at low frequencies and room temperature. Some of the data below are from this work. The following values were used in equation 11.

For Comp B -

$$S = .3 \; cal/gm \; ^\circ C$$

$$k = 3$$

$$E = 8 \times 10^6 \text{ volts/meter}$$

$$f = 50 \times 10^6 \text{ cycles/sec}$$

$$\text{Tan-}\theta\text{-} = 4.5 \times 10^{-2}$$

$$\rho = 2 \text{ gm/cm}^3$$

Computing then $\dfrac{\Delta T}{t} = 4700^0\text{C/sec}$. This is the most rapid rate of heating
that can be achieved in Comp B at 50 megacycles per second no matter how
much power is available. Additional power permits larger masses of explosive
to be heated at this rate. Of course attempts to heat more rapidly by
applying larger voltages will result in dielectric breakdown. Nevertheless
higher rates can be achieved by using higher frequencies. However, to go
appreciably above 50 mc/sec may introduce additional difficulties in circuit
design and construction.

The power per unit volume is obtained from eq. 7 or eq. 8.

$$7) \quad \frac{P_k}{V} = \frac{\pi \, \xi \, k \, f \, E^2}{10^9} \text{Tan} \;\; \text{-}\theta\text{-}, \quad \text{watt/cm}^3 = 12 \; \text{kw/cm}^3$$

Then for one gram of Comp B the power required for maximum heating rate
is 4 kilowatts.

Since the parameters used in the calculation are frequency and temper-
ature dependent these results are approximate and subject to revision.

In conclusion the calculated heating rates and power requirements
suggest that this technique has valuable applications in the explosives
laboratory. The most apparent application is to the determination of
induction time as a function of temperature for the short times. Presently
induction times much below $\frac{1}{2}$ second are in considerable doubt.

With dielectric heating a temperature stop can be applied to the
sample. Thermocouples for measuring sample temperature need not have
a response of the order of the temperature rise time of the sample because
the plateau would fall off very slowly. However, in the case of explosives,
thermocouples must be fast enough to permit the measurement to be made before
detonation occurs. Since the heat is generated uniformly through the volume
of the sample thermal gradients arise from heat loss only. this effect can
be minimized by a suitable choice of environment. In order to prevent
electrical breakdown the surrounding must have greater dielectric strength
(more properly dielectric strength times path length) than the sample.
From both considerations, an evacuated container with internally reflecting