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SELF-IGNITION PROPERTIES OF TWO PROPELLANT TYPES

by

A. F. Robertson and J. Loftus

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ABSTRACT

Measurements have been made of the kinetic data and thermal properties of two solid propellants. Using the measured data, estimates are provided of the maximum pile size and surface temperature which should be considered on the verge of critical. Prolonged storage under conditions of either greater bulk size or higher surface temperatures is considered likely to be hazardous.

1. INTRODUCTION

A current extensive research investigation, designed to assist in the solution of fire hazard problems associated with the military use of a variety of fuels and oxidizing agents, includes a study of the ignition properties of solid propellants. In connection with this program, particularly as concerned with possible hazards in the storage of propellant materials, a study of the self-heating characteristics of two representative propellants, one a double base type and the other a composite type, has been made.

2. MATERIAL

The materials furnished by the Navy were identified as a double-base propellant from Allegheny Ballistics Laboratory identified as AFD 1136, and a composite propellant from Aerojet Corp. identified as ANP batch 14 [illegible].

3. TESTS

Three types of measurements were made. These included thermal conductivity, specific heat, and chemical kinetic data related to the self-heating reaction. All three measurements were made on the composite propellant but due to shortage of material, only chemical kinetic data were obtained for the double base propellant. However, conductivity and specific heat data on another double base material were available and because of similar densities and physical form have been assumed applicable to the material considered here.

Thermal Conductivity

Measurements of the thermal conductivity of the composite propellant were made by means of a heat flow meter type of apparatus similar to that described by D. L. Lang in the ASTM Bulletin No. 216, September 1956 and entitled, "A Quick Thermal Conductivity Test for Insulating Materials." The apparatus used was calibrated by comparison tests on the NBS guarded hot plate apparatus.

Specific Heat

Measurement of specific heat of the composite propellant was made in the temperature range of 20 to 25°C. The measurement was made by replacing a portion of the water in a calorimeter vessel by a known weight of propellant sealed within a polyethylene envelope. The thermal response of the system, resulting from the introduction of known amounts of heat by electrical means, was then measured.

Chemical Kinetic Data

Measurement of activation energy and rate constant data were made with the aid of a small adiabatic furnace. The furnace and its controls were constructed to maintain a furnace temperature closely following, at all times, that of the center of the specimen. Thus, loss of heat from the specimen became negligible, and the whole specimen was allowed to heat at the same rate. The conditions established approach, therefore, those which exist in an infinitely large sample of the material, and permit a study of the behavior which may be expected in large quantity or highly insulated storage.

The test specimen with thermocouples mounted at the center and near the surface was mounted within the furnace chamber. The air temperature within the furnace was indicated by a thermocouple mounted below the specimen, and during the initial warm-up period, a constant selected furnace temperature was maintained by a thermostatic controller. After the interior of the specimen had attained the temperature of the air in the furnace chamber, any further increase in the specimen temperature automatically disconnected the thermostatic controller and initiated

operation of a servo-controller which supplied heat as needed to maintain the smallest possible temperature difference between the interior of the specimen and the gases in the furnace. A continuous chart of the temperatures within the specimen and in the furnace was obtained by means of an automatic recorder and the specimen temperature was plotted against time to give a time-temperature curve characteristic of the material. A more convenient expression of the data may be developed in the form

$$\ln\frac{dT}{dt} = \ln\frac{A}{\rho c} - \frac{Q}{T}$$

where T = absolute temperature
t = time
A = rate constant
ρ = density of the specimen
c = specific heat
Q = an activation constant divided by the gas constant,

from which it is evident that $\ln\frac{dT}{dt}$ plotted against $\frac{1}{T}$ gives a straight line having a slope of $-Q$ and intercepting the $\ln\frac{dT}{dt}$ axis at $\ln\frac{A}{\rho c}$.

In performing these tests cylindrical specimens of 2 in. in length were used. Initial furnace temperatures from which the specimens self heated to destruction were 110°C and 175°C, respectively, for double base and composite propellants, respectively. The temperature just prior to explosion was 159° and 242°C, respectively, for the propellants taken in the same order.

4. RESULTS

Table 1 presents the results of the measurements made on the thermal properties of the two propellant materials. These data were then used to compute critical size and temperatures, in the manner suggested by Enig, Shanks, and

Southworth in their paper, "The Numerical Solution of the Heat Conduction Equation in the Theory of Thermal Explosions" NAVORD Report No. 4377., November 1956. The computations were made for the radius and surface temperature of spherically shaped piles. The results of these computations are tabulated in Table II. While these computations are for the radius of a spherical pile, the corresponding values of the critical radius of a cylindrical pile and the critical half thickness of a pile in the form of a slab may be computed by multiplying the radius of the sphere by constants of 0.78 and 0.51 respectively.

Table II also presents data on the rate of self heating observed during the adiabatic furnace tests. These data are included only for informational purposes

5. SUMMARY

From measurements made on thermal properties of two propellant materials, estimates have been made of the critical size and surface temperatures of spherical piles of these materials. These conditions are considered critical in the sense that an increase of either size or temperature while the other remains constant, will, if sufficient time is allowed, result in a thermal explosion as a direct result of self heating.

TABLE I

Thermal Properties

of

Two Propellants

Propellant		Double Base AAP No. 3336	Composite AAP No. 14[illegible]-3[illegible]
Density	gm/cm^3	1.56	1.69
Thermal conductivity	cal/sec cm°C	5.3×10^{-4} *	8.1×10^{-4}
Specific heat	cal/gm°C	0.30 *	0.32
Activation energy	cal/mole	$46. \times 10^3$	$22. \times 10^3$
Rate constant	cal/mole °K	3.8×10^{22}	6.5×10^7

* Sufficient material was not available for measuring these properties of this propellant. The values shown were estimated from the results of measurements on very similar material

TABLE II

Computed Critical Pile Sizes

and

Adiabatic Heating Data

for

Two Propellant Materials

Propellant		Double Base [illegible]	Composite [illegible]
Critical radius in feet at	20°C	1660	62
	43°C	41.5	14
	82°C	2.06	3.1
	100°C	0.433	1.6
Adiabatic heating °C/min at	120°C	0.14	--
	130°C	0.70	0.01
	140°C	1.5	0.03
	150°C	explosion	0.18
	180°C		0.26
	200°C		[illegible].72
	220°C		2.32
	242°C		explosion