ON THE SURFACE PREHEATING OF BURNING EXPLOSIVES

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According to present ideas (Ref. 1) explosives burn in the following manner. The nitrocellulose dissociates in the uppermost layer of the explosive, the products of dissociation escape and react in the gaseous phase, i.e. above the surface of the explosive. Thus the primary heat release takes place in the gaseous phase, in which also the high combustion temperatures are realized. Analogous to this model is the model of combusting liquid matter, advanced by A.F. Beliaev (Ref. 2)(there exist some characteristic phenomena peculiar to combusting explosive, but these we will neglect).
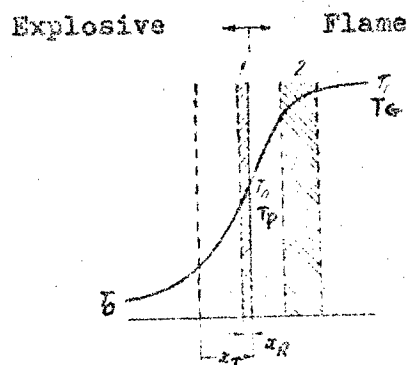
The temperature distribution on the surface of a combusting explosive, in the above graph, is based on a theory developed by J.B. Zeldovich (T_o - temperature of the explosive, T_p - temperature on the surface of the explosive, T_G - com-

bustion temperature). Chemical reactions are taking place in the shaded areas: in zone 1 - gasification of the explosive, in zone 2 - mutual reaction of the gases escaping from the explosive. A preheated layer, x_T, has to exist near the surface of the explosive, the thickness of which is equal to $\frac{\chi}{v}$, where χ - the thermal diffusivity of the explosive and v - the combustion velocity of the explosive.

One of the authors was successful in showing that the preheated layer really exists, and that its thickness corresponds to the predictions of Zeldovich's theory (0.2 mm when burning at atmospheric pressure). The goal of the present investigation is to measure the amount of heat contained in the preheated layer near the surface of the explosive, and to obtain an estimate of the temperature on the surface of the combusting explosive.

The amount of heat contained in the preheated layer was calorimetrically determined. A burning sample of the explosive was placed in a miniature calorimeter. Measured was the heat liberated in the calorimeter, which was equal to the available heat in the uppermost layer of the explosive. The error, arising from the fact that inside the calorimeter a part of the heat of combustion could escape, is small. For, separate experiments, photographing with spark photography the instant of dropping the burning explosive into the calorimeter liquid, have shown that the explosive is extinguished in the calorimeter sufficiently fast. The same experiments were performed with the burning explosive being extinguished prior to loading the calorimeter. The experiments were conducted with a pyroxylene type explosive (burning in air) and a nitroglycerin type explosive (burning in a CO_2 atmosphere). The samples of the explosives used were measured for heat capacity, heat conductivity, and combustion velocity, values essential for such calculations.

The measurements gave the following values for the amount

of heat contained in 1 cm^2 of preheated layer:

pyroxylene type explosive - 2.55 $\frac{cal}{cm^2}$ ± 0.52

(a mean over 19 experiments)

nitroglycerin type explosive - 3.32 $\frac{cal}{cm^2}$ ± 0.5

(mean over 11 experiments)

The temperature T_p on the surface of the burning explosive can be estimated from the amount of heat measured. For this purpose it is necessary to know the temperature distribution in the preheated layer of the explosive. There is no reason to doubt that the temperature distribution would not be the solution of the heat conductivity equation, the latter being given in the above mentioned work by Zeldovich:

$$T - T_o = (T_p - T_o)\, e^{-\frac{v}{\varkappa} x} \tag{1}$$

This equation is the result of assuming a thermally neutral reaction of the gasifying explosive. An exothermal reaction results in a change in distribution in the shaded part of the layer on the graph. The change leads to a measured T_p smaller than the T_p computed from equation (1):

$$T_p = T_o + \frac{Q \cdot v}{\lambda} \tag{2}$$

Where λ - heat conductivity of the explosive

Q - amount of heat in the preheated layer

Equation (2) leads to the following temperature values on the surface of a combusting explosive:

pyroxylene type explosive 525°K ± 48°

nitroglycerin type explosive 603°K ± 45°

Thus it happens that the surface temperature of a burning explosive is rather low. This corresponds to direct observations: the surface of a burning explosive does not shine during the

combustion. (We, together with A.I. Korotkov, performed some experiments during which a thin thermocouple was held onto the surface of a combusting explosive. The reading was 320° C, i.e. 593° K. The measurements with this thermocouple are only rough, but they show a correct order of magnitude.)

Furthermore, we estimated the temperature on the surface of the explosive, using the kinetic distintegration law of nitrocellulose. The speed with which nitrocellulose disintegrates in the uppermost layer of the explosive has to correspond to the combustion velocity of the explosive. If τ be the time required for the nitrocellulose to disintegrate, then the following condition has to be met:

$$\tau = \frac{x_R}{v} \tag{3}$$

with x_R the thickness of the gasification zone. Furthermore, we can obtain for x_R the expression:

$$x_R = x_T \frac{R\, T_p^2}{E(T_p - T_o)} \tag{4}$$

with E — energy required to start the nitrocellulose disintegration.

Using data on nitrocellulose disintegration, given by Vill (Ref. 3), we obtain the following expression for τ :

$$\tau = 1.67 \cdot 10^{-20}\, e^{\frac{48\,000}{RT}}$$

A value of E = 48 000 means that, according to equation (4), x_R makes up only 5% of the total thickness of the preheated layer. Thus, when combustion takes place at atmospheric pressure, the disintegration of nitrocellulose occurs only within a layer of o.ol mm thickness and no disintegration can be found in the remaining o.2 mm of the preheated layer.

Using the above equation for τ we obtain from equation

(3) a value of

$$T_p = 575^\circ \text{ K},$$

which is in accordance with the value of T_p obtained from measurements of the amount of heat in the preheated layer of the explosive.

SUMMARY:

1) The heat contained in the preheated uppermost layer of burning explosives was measured. It is equal to 2.55 and 3.32 $\frac{cal}{cm^2}$, respectively, for the two samples of explosives examined.

2) The temperature on the surface of burning explosives was found from the amount of heat measured. It was equal to 525 and 603° K, respectively, for the two samples of explosives examined.

3) Estimates of the temperatures on the surface of burning explosives, obtained through an independent method – from the kinetics of disintegration of nitrocellulose – resulted in values similar to those given in part 2, (575° K).

Given on
22 June 1946

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