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EFFECT OF TEMPERATURE OF THE SPECIFIC RATE OF BURNING OF SMOKELESS POWDER

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Abstract

A new equation for the specific rate of burning as a function of the temperature is developed. Constants in the equation are determined directly from the experimental data.

Former theories[1, 2] concerning the effect of temperature on the specific rate of burning have assumed that it is necessary to evaporate the volatiles from the powder before it will burn. Since the critical pressure of both water and ethyl alcohol are low compared to the pressures developed in a gun, almost immediately after ignition the pressure of the powder gas will be above the critical pressure* of these substances and no change of phase will occur. Hence to cause the powder to burn it is necessary only to raise it to the ignition temperature.[3]

1 L. S. Dederick - Specific Rate of Burning of Smokeless Powder.
2 W. H. Tschappat - Ordnance and Gunnery. p. 116.
3 Crow and Grimshaw - The Combustion of Colloidal Propellants. Phil. Trans. Roy. Soc. Vol. 230.

*

	Crit. Press.	Crit Temp.
Water	194.6 atmos.	365° C
Alcohol	62.7	230° C

If we consider a layer of powder of thickness, dr, the time, dt, required for sufficient heat to ignite the powder, to be transferred from the hot gases, is directly proportional to the quantity of heat necessary to raise it to the ignition temperature and inversely proportional to the rate of transfer. The amount of heat necessary to raise a layer of thickness, dr, to the ignition temperature is directly proportional to the product of the specific heat, s, of the solid powder and the temperature range, T_1-T_0, through which it is raised. As a rough approximation, the rate of transfer of heat energy from the hot gases to the powder is proportional to n', the specific energy of the powder. Therefore at a constant pressure, p, we may write

$$dt \propto \frac{s(T_1-T_0)dr}{n'} .$$

If the rate of burning is proportional to p^e then

$$\frac{dr}{dt} = \frac{cn'}{s(T_1-T_0)} p^e = K'p^e \text{ (definition of K')} \qquad (1)$$

in which c is a proportionality factor. If s, the specific heat of the solid powder, is assumed constant it may be combined with the proportionality factor c.

If

$$\frac{c}{s} = a \quad \text{then}$$

$$K' = \frac{an'}{T_1-T_0} . \qquad (2)$$

K' is the rate of combustion in inches per second measured perpendicular to the burning surface, where the powder is burning in its own gas at a pressure of 1 lb. per sq.in T_1 is the ignition temperature of the powder and T_0 is the initial powder temperature. The standard firing temperature is 21.1° C so T_0 may be replaced by the expression $(21.1+\Delta T)$ where ΔT is the difference between T_0 and 21.1°C. The denominator of (1) becomes $T_1-21.1 - \Delta T$ and if we replace

T_1-21.1 by b, equation (1) becomes

$$K' = \frac{an'}{b-\Delta T} \quad . \tag{3}$$

If a and b are constants and n' is approximately constant for each type of powder, then K' is a function of the powder temperature only. If K' may be represented by equation (3), it is obviously desirable to determine a and b from experimental data. This can best be accomplished by using the method of least squares. In order to have the expression for K' in a more convenient form, we make use of the substitutions

$$y = \frac{n'}{K'} \qquad a' = -1/a \qquad b' = \frac{b}{a}$$

equation (3) becomes

$$y = a'\Delta T + b' \tag{4}$$

a' and b' can be calculated by the method of least squares from the available temperature firings and from these a and b are determined. The specific energy, n', is computed from the composition of the powder. K' is calculated directly from the firing data with the aid of the equation from Bennett.[1]

$$q = q_o \frac{K'}{R} d^{1/2} \left(\frac{n'}{n'_o}\right)^{1/6}$$

q, the quickness is determined from the tables since the density of loading and the maximum pressure are known. R, d and n'_o are as defined by Bennett. We assume q_o is unity, since we are interested in only the change in K' for a variation in the initial temperature of the powders and q_o is not a function of the temperature.

Table I is a summary of the experimental data used in calculating a and b. Table II shows the values obtained for a and b and their probable errors for the two types of powder and also for the case in which all the available data was used without regard to the kind of powder.

[1] A.A. Bennett - Tables for Interior Ballistics.

Table III is a comparison between the computed and experimental values of $\Delta V/\Delta T$ for various guns. For each of the several gun, projectile and powder combinations, least square straight lines showing muzzle velocity as a function of the temperature are given in a report by Feltman.[1] The slopes of these lines determine the experimental values of $\Delta V/\Delta T$. The computed values of $\Delta V/\Delta T$ were obtained by calculating ΔV for a suitable interval of T from Bennett's Interior Ballistic Tables with the aid of equation (3).

Ignition Temperature

It should be noted that b is really $T_1 - 21.1$ so that $b + 21.1$ is the ignition temperature of the powder. The value of b (415) as obtained by the method of least squares from the firing records indicates that the ignition temperature is 436°C. This is much higher than the accepted value 180°C.* The accepted value of T_1 is obtained by a relatively slow heating of the powder and it is probable that T_1 is greater under firing conditions than under the conditions of slow heating.

This investigation was suggested by Mr. R. H. Kent and I am greatly indebted to him for suggestions and criticisms.

J. V. Holberton

[1] Samuel Feltman - First Partial Report on the Effect of Temperature of Powder on Velocity and Pressure. O.P. #4858. 1-Z-14.

* W. H. Tschappat - Ordnance and Gunnery, page 117.

TABLE I

	155 mm Howitzer		4.7" Gun*	75 mm 1897 Gun			
Powder	Lot 773, n' = 117x10^4		n' = 120x10^4	Lot 1164-S		n' = 119x10^4 ft.lb/lb	
Proj. Wt.	95	95	45	11.72	15.96	13.50	11.72
Charge, lb.	3.59	5.16	7.42	.61	1.51	1.61	1.32
Density of Loading	.240	.342	.820	.204	.508	.541	.441
Temperature °F	46°	46°	43°	50°	50°	50°	50°
P_{max} lb/in^2	8666	14,766	28,217	8670	32,280	34,950	22,820
q	.0778	.0852	.0500	.0893	.0991	.0977	.0899
K'	.00364	.00397	.00401	.00450	.00425	.00454	.00449
Temperature °F	59°	59°	59°	70°	70°	70°	70°
P_{max}	8733	15,650	28,383	8295	34,275	34,495	23,710
q	.0782	.0891	.0501	.0858	.1033	.0969	.0925
K'	.00366	.00416	.00403	.00433	.00443	.00450	.00462
Temperature °F	70°	70°	70°	90°	90°	90°	90°
P_{max}	9083	15,533	29,867	8340	34,320	37,260	24,410
q	.0810	.0886	.0520	.0862	.1034	.1022	.0945
K'	.00379	.00414	.00417	.00435	.00444	.00475	.00472
Temperature °F	84°	84°	83°	110°	110°	110°	110°
P_{max}	9383	16,050	30,133	8330	37,880	39,970	24,610
q	.0833	.0909	.0523	.0861	.1106	.1071	.0950
K'	.00390	.00424	.00423	.00434	.00475	.00498	.00475
Temperature °F				135°	135°	135°	135°
P_{max}				.0938	.1150	.1088	.0978
K'				.00473	.00493	.00505	.00488

* Pressures for 155 mm Howitzer and 4.7" Gun are an average of 3 rounds.

TABLE I (CONTINUED)

	75 mm 1897 Gun			3" Gun 1925		3" Gun 1918	
Powder	FNH Lot 3599		$n' = 105 \times 10^4$	Lot 2132-S		$n' = 118 \times 10^4$	
Proj. Wt.	15.96	13.5	11.72	12.7	15.0	12.7	15
Charge	27.88 oz.	29.63 oz.	24.47 oz.	4.68 lbs.	4.61	3.99 lbs.	3.84 lbs.
Density of Loading	.584	.620	.512	.437	.431	.553	.531
Temperature °F	50°	50°	50°	50°	50°	50°	50°
P_{max}	31050	32520	21230	27170	27463	34870	30620
q	.0902	.0870	.0796	.1037	.1060	.0958	.0913
K'	.00394	.00411	.00405	.00376	.00357	.00432	.00382
Temperature °F	70°	70°	70°	70°	70°	70°	70°
P_{max}	33115	35017	21965	28295	28275	34050	32835
q	.0943	.0915	.0816	.1067	.1082	.0941	.0961
K'	.00412	.00433	.00415	.00387	.00364	.00424	.00402
Temperaature °F	90°	90°	90°	90°	90°	90°	90°
P_{max}	33630	35640	21810	28570	27810	35720	33550
q	.0953	.0926	.0811	.1075	.1070	.0974	.0976
K'	.00417	.00438	.00412	.00390	.00361	.00439	.00408
Temperature °F	110°	110°	110°	110°	110°	110°	110°
P_{max}	36240	36920	22670	31260	31280	37620	36710
q	.1066	.1004	.0858	.1144	.1161	.1010	.1038
K'	.00466	.00475	.00436	.00415	.00401	.00455	.00434
Temperature °F	135°	135°	135°	135°	135°	135°	135°
P_{max}	39760	40190	23540	33480	33113	40190	38290
q	.1066	.1004	.0858	.1198	.1206	.1056	.1068
K'	.00466	.00475	.00436	.00435	.00406	.00476	.00447

Table II

Powder	a		P.e. of a	P.e. of b
Pyro	$.0170 \times 10^{-4}$	482	$.000353 \times 10^{-4}$	104
FNH	$.0160 \times 10^{-4}$	405	$.00191 \times 10^{-4}$	50
Pyro or FNH	$.0149 \times 10^{-4}$	415	$.00258 \times 10^{-4}$	75

Equation for K'

$$K' = \frac{.0149n' \times 10^{-4}}{415 - \Delta T}$$

Table III

Comparison of computed and exp. values of $\Delta V / \Delta T$

Gun	Type of Powder	Muzzle Vel. at 70° F	$\frac{\Delta V}{\Delta T}$ in ft/sec/deg F	
			Exp.	Computed
3" A.A. 1925	Pyro	2485	.91	.89
75 mm 1897	Pyro	1735	.60	.53
75 mm 1897	FNH	1805	.59	.86
75 mm 1897	Pyro	1097	.69	.53
155 mm How. 1918	Pyro	862	.70	.57
3" A.A. 1918	Pyro	2330	1.22	1.28

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