(*Paper No. 2390.*)

“Perforated Cake-Powder for Ordnance.”

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(*Abstract.*)

THIS Paper describes a new modification of powder, by means of which it is proposed to obviate some of the disadvantages of the powders now in use for military purposes. Among such disadvantages are mentioned the large amount of heated, and sometimes fused, residue left in the gun, the irregularity of the velocity and pressure produced, and the erosive action upon the bore of the gun. Although the brown or cocoa powder gives better results in general, in regard to moderate pressure than black powder, yet the amount of residue which it leaves is greater. The Author claims that his method of forming the “propelling material” is equally applicable either to the new chemical propelling materials or to the old varieties of powder.

After considering the relation between the pressure and expansion of the gases produced by the combustion of powder in the bore of a gun, the conclusion is arrived at that the best results are to be looked for by using a slow-burning powder rather than by increasing the air-spacing of the charge. The rate of burning of a powder is dependent upon various modifications during manufacture, and upon the pressure of the atmosphere of fire to which it is exposed. With most powders the area of combustion-surface decreases as the time increases, while the object to be aimed at is that the pressure shall very rapidly reach its maximum, which shall be maintained constant till the completion of combustion. By making the surface increase as combustion proceeds the pressure can be made approximately constant during the time combustion is proceeding. When a cylindrical block of powder, pierced by a hole, is burnt, the surface will decrease as time increases; but if, in addition to the centre hole, a number of smaller ones are ranged round it then it will be possible to prevent the surface from diminishing as combustion proceeds, and it may even be increased. The form of powder proposed by the Author, and of which illustrations accompany the Paper, is that of circular disks with one central circular perforation of considerable size and three

concentric circles of smaller perforations, also circular in section. Alternate quadrants of the cake are in relief, so that when two cakes are placed together the raised quadrants of the one fit into the sunk ones of the other, and the two cakes are in a manner locked, so that all the perforations are in line parallel with the axis through the whole length of the cartridge. The quadrants are dished, or somewhat hollowed out towards the centre, to permit of the flame readily reaching the whole surface of the cakes. In forming a cartridge a number of these cakes are united by means of a waterproof cement, which is highly combustible and leaves only a very small amount of residuum. With ordinary powder the ignition of long cartridges from their rear ends is said to rupture the powder in front, crushing it into very small fragments, which cause excessive local pressures. To obviate this difficulty large air-spacing has been used; but this has diminished the amount of energy obtained per lb. of powder, and consequently increased the weight of the gun and breech mechanism, by reason of the large diameter of the powder-chamber required for this large air-spacing. With the new form of powder proposed by the Author, a higher gravimetric density of the charge is said to be obtained, together with a higher velocity and lower pressure. It is calculated in the case of a 6-inch gun that an economy of 15·7 per cent. may be effected in the weight of metal. A pressure not exceeding 20 tons is recommended for the powder-gas in the gun, it being considered probable that higher pressures may increase the erosion of the bore and deteriorate the metal by changing its molecular condition.

The Author believes that the pressure generated in the bore of a gun, charged according to his system, may be so regulated that it would be possible to discharge shells containing high explosives such as dynamite. Although the calculations are made on the assumption that the perforated powder-cakes will not break up during the period of combustion, yet it is not expected that this will be found mathematically true in practice. The experiments which are referred to show, however, that the assumption is true enough for all practical purposes.

The Author summarizes the conclusions which he has arrived at as follow:—1. The pressure should, if possible, be maintained at its maximum till the projectile has travelled some considerable distance up the bore. 2. This can be most satisfactorily obtained by using a powder whose surface of ignition increases as combustion proceeds, or remains practically uniform. 3. That a comparatively low maximum pressure should be adopted if the best results, in the fullest sense of the term, are to be obtained. 4. That the density

of the powder should be very high so as to secure uniformity of combustion, and that the initial ignition and terminal combustion surfaces should be large enough to secure a sufficiently rapid combustion of this very dense and slow-burning powder, so that none may be blown out of the gun in an unconsumed state.

5. That the air-spacing should be reduced to the lowest possible amount compatible with the due ignition of the charge, and with a sufficient channel space to allow of a fair flow of the powder-gas direct to the base of the projectile as soon as the charge is ignited.

6. That the powder-charge should be so arranged that the whole of it should be simultaneously ignited, in order that each and every element (cake) should be surrounded by an atmosphere of fire equal in pressure in all directions.

It has been estimated by Nobel and Abel that the time occupied by the projectile in moving 1 foot is 0·005 second, while Sébert and Hugoniot show that the maximum pressure varied from 1,400 atmospheres to 2,400 atmospheres, and was reached in periods of time varying from 0·004 second to 0·001 second according to the resistance of the rotating ring of the projectile. The hydraulic pressure required to push the ordinary rotating ring into the rifling of a 3- to 5-inch calibre gun is about 1 ton per square inch of the cross-section of the projectile. The projectile should, therefore, begin to move the instant the gas-pressure behind it reaches 1 ton per square inch. With the Author's cake-powder and cartridge the gas has direct access to the base of the projectile, by virtue of the large air-spacing in the centre, and all the other perforations being in line through the whole length of the cartridge. As combustion proceeds the perforations increase in area, and as the projectile is constantly moving away, the pressure cannot rise very high. This arrangement of the air-spacing causes the work to be done on the projectile instead of being wasted in crushing the powder.

A statement of the area of the combustion-surface of 42-lb. charges of different kinds for a 6-inch gun is given as follows:—

(a.) 1·5-inch cubes of powder, averaging six to the lb. P_2 powder, density 1·75.

(b.) Hexagon powder, 0·976 inch high, 1·367 inch over sides, with central perforation 0·394 inch in diameter. Prism powder, density 1·75.

(c.) Quick perforated cake-powder, 6·7 inches in diameter, thickness or length on axis 1·7 inch, with central perforation 2·5 inches in diameter, and sixty other perforations 0·25 inch in diameter, density 1·75.

(d.) Quick perforated cake-powder 7·7 inches in diameter, thickness or length on axis 1·75 inch, with central perforation 1·0 inch in diameter, and seventy-two other perforations 0·3 inch in diameter, density 1·75.

(e.) Quick perforated cake-powder 7·7 inches in diameter, thickness or length on axis 1·75 inch, with central perforation 2·5 inches in diameter, and thirty-three other perforations 0·25 inch in diameter density 1·80.

1	2	3	4	5	6	7	8	9	10	11	12	
Description of Charge.												
	Length of Charge.		Area of initial Ignition Surface.		Area of combustion surface when half the weight of the charge has been consumed.		Area of combustion surface when half the time of combustion has expired.		Area of combustion surface at the instant of final dissolution.		Half of least thickness of powder pellet or cake burnt through.	
	Ins.	Sq. Ins.	Ins.	Sq. Ins.	Square Inches.	Square Inches.	Inch.	Seconds.	Ins. per Sec.	Seconds.	Lbs.	Lbs.
a	26	3,400	2,120		850	0	0·75000	1·8750	19·05	0·03936	37·29	4·71
b	26	3,995	2,960		2,730	300	0·24325	0·6081	20·40	0·01192	25·37	16·63
c	26	2,580	2,930		2,860	2,920	0·20000	0·5000	16·59	0·01205	15·20	26·80
d	20	2,600	3,140		3,010	3,150	0·20000	0·5000	16·60	0·01205	15·65	26·35
e	21	2,178	2,172		2,240	1,813	0·35000	0·8870	15·25	0·02292	20·60	33·90

In preparing this Table the velocity of combustion, shewn in col. 9, has been calculated for the pressure of the atmosphere of fire in which the combustion is effected, on the assumptions of Mr. Castan. According to Mr. Castan, 0·4 inch of solid powder will be burnt in one second under atmospheric pressure; but at the usual pressure of the atmosphere of fire in large guns the mean velocity of combustion is about thirty-two times as great, or 12·8 inches per second, but the actual velocity is probably much greater than this.

In 1860 General Rodman, of the United States, designed a perforated cake-powder for ordnance; but the Quick cake-powder differs from the Rodman powder as follows:—(1) All the cakes are

interlocking; (2) they have a large central orifice to provide for a rush of the gas directly to the centre of the base of the projectile; (3) the faces of the central parts of the cake are hollowed to permit the flame of ignition to spread radially; and (4) the cementing of the cakes together to form a rigid cartridge.

From the figures given in the Table it will be seen that the gas-generating surface of the Quick powder is at a minimum when the resistance of the projectile is at a maximum, and in the case of *c* and *d* the gas-generation steadily increases as the projectile rushes up the bore. It is claimed that with the Author's system a black powder of high density may be used, and this is stated to be an advantage, because a larger amount of energy has been obtained per lb. of black powder than has been obtained per lb. of any cocoa or brown cannon powder.

A Table is annexed to the Paper containing selections from a number of experiments made with Quick cake-powder in a 3-inch experimental quick breech-loading gun.

In round 29, when the size of the chamber was 145 cubic inches, the efficiency of the powder was 71 foot-tons; while in round 79, after the volume of the chamber had been increased to 180 cubic inches, the efficiency was reduced to 56·6 foot-tons per lb. of powder. A theoretically perfect propelling material does not exist, nor is it likely to be discovered; but by the perforated-cake formation of the black material the following advantages are obtained:—

1. The complete ignition of the whole charge is effected simultaneously.
2. A uniform or increasing area of combustion with corresponding pressure may be obtained.
3. The pressure and ballistic effects of a given weight of this black powder are far higher than with a similar weight of brown cake-powder under the same conditions.

Figures from the Table of experiments are given to confirm this.

The larger and longer a gun is, and the greater the weight and resistance of the projectile, the more dense may be the powder-cakes, providing the material will burn with sufficient rapidity to be converted into gas before the projectile has accomplished more than 43 per cent. of its travel in the gun. If the projectile be of the same proportionate length and the guns be also of the same proportionate length, and the muzzle velocity be the same, then the time of travel up the bore will be directly in proportion to the length of the guns.

Piobert's law, as to the velocity of combustion of powder of very high density, appears to give too low results, and it seems that

the time of complete combustion of the charge of a 6-inch gun should not exceed 0.0062 second if the projectile weighs 100 lbs. Although Quick powder of high density does not give too high a pressure, yet it is found that prism powder of low density and large size produces abnormally high pressures, due probably to the large prisms being split up by the hot gases. With prism powder of high density and small size the large initial ignition surface causes danger, from high initial gas pressure at the instant when the projectile has but a very small velocity.

A 100-lb. charge composed of 1-inch cubes would have an initial ignition surface of 9,600 square inches, and by substituting $\frac{1}{2}$ -inch cubes the surface will be increased to 19,200 square inches.

With the cake-powder the time of combustion of the whole mass may be regulated by making the perforations more or less numerous. It is advisable to make the cakes of as high a density as possible, to diminish the chance of their being broken up into small fragments.

For naval service it is of great importance that the size of the charge shall be as small as possible, so that a greater number of charges may be carried in the magazine.

When cemented, waterproofed, and made into charges, the Quick cake-powder has some practical advantages over the usual cartridges. Hexagon, prism, or pebble powder cannot be made into rigid cartridges to fit the chamber. Cartridges made from these varieties of powder are polygonal and have angles which are liable to cut the canvas and produce dust and, perhaps, premature explosions. The Author's cartridges can be made to fit the gun, and may be cemented into one rigid mass. A shield or wad of non-inflammable material may be fixed to the front end, so that any small amount of burning residuum would be swept forward by it out of the way of the powder.

Brown and cocoa powders are said to deteriorate when kept for any considerable periods in extreme climates. The bursting of a 34-centimetre gun on board the "Amiral Duperré" is ascribed to the change which had taken place in the powder, due to the heat of the magazine. An increase of powder-pressures has also been observed in the guns of H.M.S. "Impérieuse" on the China station. The percussion locks in the breech-blocks having been constantly blown out, experiments with crusher-gauges were made, and it was found that the pressures of the charges were greatly in excess of what ought to be the case with slow-burning powder.

SELECTIONS from EXPERIMENTAL ROUNDS with 3-inch BREECH-

Date of Trial.	Number of Round.	Description of Powder.	Weight of Charge.	Weight and Description of Projectile.
			Lbs.	Lbs.
4/5/87	16	Quick's cake, experimental, No. 3 . . .	6·500	12·50
"	17	Ditto " . . .	6·500	12·50
"	18	Ditto " . . .	6·500	12·50
"	20	Ditto " . . .	6·500	12·25
"	21	Ditto " . . .	6·500	12·25
18/6/87	27	Ditto, experimental, No. 1	6·500	12·00
"	28	Ditto " " 2	5·625	12·00
"	29	Ditto " " 3	5·500	12·00
"	30	{Ditto, mixture of, experimental, Nos. 2 and 3}	6·125	12·25
15/11/87	34	Ditto, experimental, No. 3 (This powder had been exposed to the atmosphere of the temporary magazine for five months.)	8·250	12·14
14/3/88	38	Ditto, experimental, No. 4 (<i>Special rapid-burning powder, ce- mented.</i>)	4·000	12·25
21/3/88	40	Ditto, experimental, No. 5 (<i>Special rapid-burning powder, ce- mented.</i>)	6·000	12·00
"	41	Ditto, experimental, No. 4 (<i>Rapid-burning powder, cemented.</i>)	6·000	12·00
"	42	Ditto, experimental, No. 3, not protected	6·000	12·00
"	43	Ditto, experimental, No. 4 (<i>Rapid-burning powder, cemented and waterproofed.</i>)	4·000	12·00
23/3/88	50	Ditto, experimental, No. 6 (Medium burning powder, not ce- mented.)	6·000	12·00
"	51	Ditto, experimental, No. 4 (<i>Rapid-burning powder, cemented and waterproofed.</i>)	4·000	12·00

LOADING GUN and PERFORATED CAKE-POWDER.

Velocity Observed.	Recoil.	Pressure at Rear of the Chamber.	Pressure at Base of the Projectile.	Remarks.
Foot-secs.	Feet. Ins.	Tons per Square In.	Tons per Square In.	
2,081	12 3	..	..	{ Old wood platform. Inclination of slide 1 in 12. Ditto. Ditto. Ditto. Ditto.
2,080	12 3½	..	..	
2,094	12 3	..	..	
2,107	12 0	..	..	
2,136	12 0	..	..	
2,050	9 10	..	{ Did not exceed 14 tons }	{ Ditto. Inclination of slide altered to 1 in 6. Ditto.
2,000	9 3	..	..	
2,145	8 11	..	14·05	Ditto.
2,130	10 6	..	Shot lost	Ditto.
..	12 8	..	13·80	Ditto. Powder-chamber enlarged, by lengthening, from 14·500 to 18·125 inches, and volume increased from 145 to 180 cubic inches.
..	1 3	{ Did not exceed 13 tons }	{ Not taken }	{ New Anderson's recoil carriage. Ditto, adjusted.
1,917	0 8	{ 14·98 mean }	..	
2,011	0 8	{ 16·80 mean }	..	{ Anderson's recoil carriage. This cartridge was placed in water for four minutes, and was wet for 10 minutes before firing. It occupied only one half of the length of the chamber, the rear half of the chamber being empty. Anderson's recoil carriage, readjusted.
1,855	0 7¾	{ 14·75 }	..	
1,704	0 7¾	{ Not taken }	..	
2,050	0 9½	..	..	
1,654	0 9	..	..	This cartridge was soaked in water for 45 minutes. The first primer failed to ignite the charge, second primer fired it. This cartridge did not half fill the chamber, a length of 8 inches being left from the rear end of the cartridge to the face of the breech-screw.

SELECTIONS from EXPERIMENTAL ROUNDS with 3-inch BREECH-

Date of Trial.	Number of Round.	Description of Powder.	Weight of Charge.	Weight and Description of Projectile.
23/3/88	52	Quick's cake, experimental, No. 7 . . . (Mixture or combination of various densities.)	Lbs. 6·750	Lbs. 12·00
"	53	Ditto, experimental, No. 8 (Mixture of slow and rapid-burning powders.)	6·750	12·00
"	54	Ditto, experimental, No. 9 (Mixture of slow and rapid-burning powders, not cemented.)	6·625	12·00
"	57	Ditto, experimental, No. 6	8·000	12·00
27/3/88	59	{Ditto, experimental, Nos. 2 and 3} { mixed }	5·560	12·00
"	60	Ditto, experimental, No. 4	6·000	12·00
"	61	Ditto " " 3	6·500	15·00
"	62	Ditto " " 4	7·000	12·00
10/5/88	73	Ditto " " 6 (Cemented and waterproofed.)	6·000	12·00
18/5/88	75	Ditto, experimental. No. 10 (Black powder, not cemented. <i>Special rapid-burning powder.</i>)	5·000	12·25
"	76	Ditto, experimental, No. 6 (Black powder, waterproofed.)	5·000	12·25
"	77	Ditto, experimental, No. 10 (Black powder, not cemented. <i>Special rapid-burning powder.</i>)	6·875	12·25
(See for comparison rounds 27, 29, 57, 59, and 61.)				
"	78	Ditto, experimental, No. 11 (Brown powder not cemented.)	5·250	12·25
"	79	Ditto, experimental, No. 10 (Black powder not cemented. <i>Special rapid-burning powder.</i>)	5·000	12·00

LOADING GUN and PERFORATED CAKE-POWDER—continued.

Velocity Observed.	Recoil.	Pressure at Rear of the Chamber.	Pressure at Base of the Projectile.	Remarks.
Foot-secs.	Feet. Ins.	Tons per Square In.	Tons per Square In.	
2,064	0 9 $\frac{3}{4}$	..	..	Anderson's recoil carriage.
2,100	0 9 $\frac{3}{4}$	..	..	Ditto.
2,050	0 9 $\frac{3}{4}$	..	..	Ditto.
2,250	0 9 $\frac{3}{4}$	..	..	Ditto.
..	0 11 $\frac{1}{4}$	Did not exceed 13·78 tons	..	{ Anderson's recoil carriage, again re-adjusted.
..	0 11 $\frac{1}{2}$	15·37	..	
..	0 11 $\frac{5}{8}$	Did not exceed 13·78 tons	..	
..	0 11 $\frac{3}{4}$	17·90	..	
..	0 11 $\frac{3}{4}$	..	..	No difficulty in ignition, although cartridge was soaked in a bucket of water for 33 $\frac{1}{2}$ minutes.
..	1 0	17·50	..	
..	0 11 $\frac{7}{8}$	13·80	..	This cartridge was soaked in a bucket of water for 1 hour 50 minutes.
2,118	1 0 $\frac{1}{2}$	23·20	..	<i>This round was fired with the view of severely testing the strength of the breech mechanism. There was not the slightest sign of weakness, of jamming of the breech, of the firing mechanism, nor of the extracting gear for the vent-sealing firing-tube. The breech was opened with two fingers only. There was no escape of gas.</i>
1,435	0 11 $\frac{3}{4}$	Did not exceed 13 tons	..	{ Much residuum, of a salt-like appearance, principally up the bore of the gun.
1,845	1 0 $\frac{1}{2}$	16·80	..	