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# SMOKELESS POWDERS, OF NITRO-GLYCERINE TYPE

*By L. PONCET, Lieutenant d'Artillerie.*

Translated from the "Revue d'Artillerie" by Fleet-Engineer  
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THE evolution in the manufacture of powders for war purposes, which originated in 1885, and was commenced by France, has been continued abroad, and consists in the employment of nitrated organic explosives of great power; these explosives, whether employed in fire-arms or mines, produce the same effect as charges of black powder three or four times larger, and have the advantage besides that they do not disengage any smoke in deflagrating—a very important qualification from a tactical point of view.

It was at the end of 1884 when, thanks to the researches of M. Vieille, a process of manufacture for a smokeless powder, based on the employment of nitro-cellulose in a colloidal state, was initiated at the Central Laboratory for powder and saltpetres. This process permitted the mode of combustion of the nitrated explosives to be regulated, and as a result to allow of their employment in and adjustment for guns of any given calibre. Rendering possible in portable fire-arms with equal pressures an increase of initial velocity of 100 metres above that given with black powder, this discovery could not rest without rivalry in other countries. It was the signal for a series of experiments on the part of foreign engineers, and in 1888 the Swedish chemist Alfred Nobel obtained a patent for a smokeless powder containing nitro-cellulose and nitro-glycerine.

The known smokeless powders may be classed in three categories. First: Powders containing nitro-cellulose only; either soluble in a mixture of alcohol and ether, or insoluble, or a mixture of the two kinds. To this category belong the French powder B, the Russian powders (including the pyro-collodion powder of Mendéléyef, used in the Russian Navy), the Belgian powder of Wetteren, the German flake powder, and the Austrian Schwab powder. Secondly: Powders composed of nitro-glycerine and nitro-cellulose. To this category belong the Nobel powders (ballistite, Italian or German; filite, Italian), which are composed of nearly equal parts of soluble nitro-cellulose and nitro-glycerine, either mixed or not with one or two parts of inert substances (aniline, diphenylamine, camphor, etc.); to the same category also belongs the English cordite, composed of nitro-glycerine, of insoluble nitro-cellulose and vaseline, and the Austrian gunpowder, model 1893, composed of nitro-glycerine and insoluble nitro-cellulose. Finally, the American Maxim powder and certain other analogous powders may be classed under this head, although they contain only a very slight proportion of nitro-glycerine (5 to 10 per cent.). Thirdly: Powders composed of nitro-cellulose, mixed with nitrates

obtained from certain aromatic carburets. This category comprises only a few samples; we may instance indurite of the American professor Munroe, prepared with insoluble nitro-cellulose and nitro-benzine, and the Dupont powder of the American firm Dupont and Co., composed of the same elements. Besides these powders, of which we propose to treat, a number of others have been proposed, varying greatly in their composition; but, generally speaking, the results obtained from them have not been entirely satisfactory. Without further delay in dealing with powders of the first and third categories, we proceed with the second, or nitro-glycerine powders, which form the especial object of the present article.

*Composition and Properties of the Principal Nitro-Glycerine Powders, Nobel Powders, or Ballistite.*—The Nobel powders, which have been experimented with by different countries since 1889, have given good results from a ballistic point of view. When used in guns they have even proved superior in this respect to pure nitro-cellulose powder. In spite of the favour with which they have been regarded for some time abroad, Italy is the only country where they have been adopted exclusively as the regulation powders. We are already aware that the Nobel powders are composed of a mixture in nearly equal parts of soluble nitro-cellulose and nitro-glycerine. This composition has been adopted by reason of the influence exercised on the consistency of the mass by the excess of one or the other of those substances. If there are more than two-thirds of nitro-glycerine in the powder it becomes soft and too plastic; if, on the contrary, there are more than two-thirds nitro-cellulose the substance becomes hard and difficult to granulate. The first samples of powder prepared by Nobel contained 70 per cent. of nitro-glycerine and 30 per cent. nitro-cellulose; for these reasons we propose to point out what has led up to the actual composition. The addition of a small quantity of camphor, 1 to 2 per cent., moderates the rapidity of combustion in the chamber, and reduces the sensibility to shock. The evaporation of the camphor, however, which always takes place in time, causes these advantages, little by little, to disappear, and the powder therefore does not remain constantly comparable in its results. With the view of lessening this inconvenience, the quantity of camphor was at first reduced to  $\frac{1}{4}$  or  $\frac{1}{2}$  per cent., and then replaced either by tannin or aniline, particularly in the Italian ballistite. At the commencement the nitro-cellulose employed by Nobel in his powders was ordinary collodion, and contained from 11 to 12 per cent. of nitrogen (azote). Since 1893 the Nobel manufactures have succeeded in making soluble nitro-cellulose, containing from 12 to 12·2 per cent. of azote, which, as we shall see further on, has permitted of the explosive effects of the powder being increased. Powders of the Nobel type for portable arms are in the form of cubical grains of dimensions varying according to the calibre and of a dark cherry-red colour. For the Italian Vetterli rifle the grains are ·9 millimetre thick, for the revolvers only ·2 millimetre. The powders for big guns are in the form of prisms of square section, whether in sheets or threads: in the latter case it is called filite. This is also employed in Italian artillery.

*Cordites*.—In England the nitro-glycerine powders have been, in a general manner, the name, or cordite when prepared in the form of filaments resembling cord. This denomination, however, is more specially applied to the powder invented by the chemists Abel and Dewar. The composition of the Abel and Dewar cordite varies with the calibre of the arm in which it is to be used. It always contains insoluble nitro-cellulose, nitro-glycerine, and vaseline; this last substance serving to lower the temperature of the explosion. The following table shows the composition of the two samples generally used:—

Powder for portable arms (filaments, .85 millimetre to .88 millimetre in diameter, and 36 millimetres in length):—

Nitro-glycerine	-	-	-	-	-	57.4 per cent.
Nitro-cellulose	-	-	-	-	-	37.0 „
Vaseline	-	-	-	-	-	5.4 „
Water	-	-	-	-	-	.2 „

Powder for guns of 12 centimetres, Armstrong (filaments, 4.5 millimetres in diameter, and 350 millimetres in length):—

Nitro-glycerine	-	-	-	-	-	56.5 per cent.
Nitro-cellulose	-	-	-	-	-	37.6 „
Vaseline	-	-	-	-	-	5.6 „
Water	-	-	-	-	-	.3 „

*Austrian Powder, Model 1893*.—This powder for field-guns of 9 centimetres has the peculiarity that it is composed only of nitro-glycerine and insoluble nitro-cellulose without the addition of any vaseline or other mineral grease, as is the usual practice with powders containing insoluble nitro-cellulose. The composition of this powder is as follows:—

Nitro-glycerine 49.4, per cent.; nitro-cellulose, 50.3 per cent.; water, .29 per cent. It has, as we see, much analogy as regards its composition with the Nobel powders; it is distinguished by the employment of insoluble nitro-cellulose. This powder is prepared in the form of grains cylindrical in shape 1.4 millimetres to 1.7 millimetres in diameter and from 3 to 5 millimetres in length. These grains are polished by graphite, which diminishes their sensibility to shock.

*Maxim Powders*.—The samples of Maxim powders proposed in 1888 by the Maxim-Nordenfeldt firm contain variable proportions, but always very weak; of nitro-glycerine; a small quantity of ricine oil is added, a carburet which tends to lower the temperature of combustion. We give below the composition of two samples of rifle powder proposed by Maxim:—

<i>Sample No. 1</i> .—Nitro-cellulose	-	-	-	94 per cent.
Nitro-glycerine	-	-	-	5 „
Ricine oil	-	-	-	1 „
<i>Sample No. 2</i> .—Nitro-cellulose	-	-	-	88 per cent.
Nitro-glycerine	-	-	-	10 „
Ricine oil	-	-	-	2 „

*Nitro-Glycerine Powders Compared with those of Pure Nitro-Cellulose.*—

The advantages of the former over the latter are very real from a ballistic point of view, and permit of greater velocities being obtained with less pressures; this is shown in the following table, which gives the results of some experiments carried out in Russia:—

Powder employed.	Russian Rifle of 3 lines = 7.62 millimetres.			Russian light Gun of 87.0 millimetres.		
	Charge.	Initial velocity.	Pres- sure.	Charge.	Initial velocity.	Pres- sure.
	Grammes.	Metres.	Atmo- spheres.	Grammes.	Metres.	Atmo- spheres.
Ballistite (in grains) ...	2.00	615	2250	629	525	1350
Cordite (Abel) ...	2.85	615	2550	—	—	—
Maxim Powder (containing only 5 per cent. of Nitro- glycerine) ...	1.95	615	2800	—	—	—
French Powder (from pure Nitro-cellulose) ...	2.45	615	2700	715	525	1400

The combustion of nitro-glycerine powders is by parallel layers and is effected in a more regular manner than that of the nitro-cellulose. This fact is due to the greater compactness of the mass and the absence of porosity in the first-named. These powders also work more easily than those of nitro-cellulose on account of their greater malleability, and can be given the most varied forms of cubic or prismatic grains, flakes, filaments, etc., and thus supply a very easy solution of the problem of how to adapt a given powder to arms of different calibres. They are also easier to make than those of nitro-cellulose, besides which the presence of nitro-glycerine as a dissolvent of the nitro-cellulose suppresses or diminishes the quantity of volatile dissolvent necessary in manufacture, and thus reduces the cost. On the other hand, from other points of view the nitro-glycerine powders have certain great disadvantages. The temperature of combustion is about 500°<sup>1</sup> higher than that of pure nitro-cellulose powders, 2,700° as against 2,200°, and this element plays a very important part in the conservation of the gun. Thus in guns of large calibres the deterioration produced by nitro-glycerine powders is sensible after the tenth round. This defect is lessened by a reduction of the quantity of nitro-glycerine as has been done in powders of the Maxim type, but such powders have little advantage from a ballistic point of view over the pure nitro-cellulose powders.

Nitro-glycerine powders appear to have a greater tendency to decomposition under the action of heat than those of nitro-cellulose. Finally, the nitro-glycerine powders of the ballistite and cordite types have the property of freezing under the influence of cold temperature of relatively small intensity. Beyond the fact that this congelation may be the cause of miss-fires it may also happen that it may cause a modification in the explosive properties of the powder.

*Properties and Mode of Obtaining Nitro-Cellulose and Nitro-Glycerine.*—

Before considering the question of the manufacture of nitro-glycerine

<sup>1</sup> All temperatures are in centigrade.

smokeless powders it will be useful to enumerate the properties of the two fundamental substances which enter into these compositions. *Nitro-cellulose* :—This is one of the elements in the constitution of all smokeless powders, and results from the action of nitric acid on the cellulose which may be in various forms (cotton, paper, straw, etc.). According to the degree of concentration of the acid we obtain the following compounds :—

$C^{24}H^{29}(NO^2)^{11}O^{20}$	endecanitic cellulose with 13·51 per cent. azote.		
$C^{24}H^{20}(NO^2)^{10}O^{20}$	decanitic	12·75	„ „
$C^{24}H^{21}(NO^2)^9O^{20}$	ennecanitic	11·93	„ „
$C^{24}H^{22}(NO^2)^8O^{20}$	octonitic	11·11	„ „
$C^{24}H^{23}(NO^2)^7O^{20}$	heptanitic	10·11	„ „
$C^{24}H^{24}(NO^2)^6O^{20}$	hexanitic	9·15	„ „
$C^{24}H^{25}(NO^2)^5O^{20}$	pentanitic	8·03	„ „
$C^{24}H^{26}(NO^2)^4O^{20}$	tetranitic	6·76	„ „

Endecanitic cellulose forms the cotton powder. It is insoluble, except in acetic ether and acetone.

Decanitic cellulose is a cotton powder almost insoluble, except by acetic ether and acetone.

Enneanitic and octonitic celluloses form the collodions; they are soluble as above and in a mixture of alcohol and ether.

The less nitrated celluloses form a friable cotton. They preserve the appearance of cotton, but become gelatinous without truly dissolving under the action of solvents. Both insoluble nitro-cellulose (cotton powders) and soluble nitro-cellulose (collodions) are employed in the manufacture of smokeless powders. Cellulose with inferior nitrification to the collodions do not detonate and cannot be used as explosives. In most of the pure nitro-cellulose powders both of the above kinds are used and yield a substance capable of being gelatinised to a certain extent in the ordinary solvents: acetic ether, alcohol and ether, etc. The explosive effect of these powders depends on the quantity of insoluble nitro-cellulose contained in the mass, for the pressures developed in a closed vessel by different kinds show that the force generated diminishes rapidly with the measure of nitrification. The proportion of azote forms a true measure of the explosive qualities of the powder. In the nitro-glycerine powders of the Nobel type, which owe their explosive force principally to this substance, only soluble nitro-cellulose is employed; and from what has been said the more this substance is azotised, while still remaining soluble, the greater is the explosive effect in equal quantities of nitro-glycerine. In Abel's cordite only insoluble nitro-cellulose is used, as already mentioned. The powder industry has thus been led to the production, both in soluble as in insoluble nitro-cellulose (cotton powder), of that which contains the largest proportion of nitric acid.

The fabrication of pure cotton powder is carried out by the process indicated about 1865 by the English chemist Abel. It is due to the labours of this expert that cotton powder, which up to this period was considered a substance very dangerous to handle, has taken such an important place in military practice. The process of Professor Abel

consists in nitrifying the cotton, previously cleaned and dried, by concentrated nitric acid and sulphuric acid, and then to eliminate all trace of the acid by washing and drying, reduce it to a paste by a pulping machine, and then to compress the cotton powder thus obtained in special moulds to give it the required forms. The great advantage of the Abel process resides in the complete elimination of the traces of acid, and in this way to insure a great stability in the cotton powder and avoid all danger in its manipulation.

*Manufacture of Soluble Nitro-Cellulose.*—The collodions are obtained by a process of manufacture analogous to that of cotton powder, but diluted instead of concentrated nitric acid is employed. Ordinary collodions are heterogeneous in composition, and contain from 11 to 12 per cent. of nitric acid (azote). We have already said that the trade has endeavoured in recent years to obtain collodions as homogeneous and nitrated as possible. The results as yet obtained are not completely satisfactory. Very often the retention of azote in the products is not constant, and different samples do not behave always in the same manner when subjected to a mixture of alcohol and ether. Whilst one sample will dissolve at once like sugar in water, the other may take the form of jelly before dissolving. The Nobel works, however, employ in the manufacture of ballistites, collodions containing from 12 to 12·2 per cent. of azote, and completely soluble. The Russian chemist Mendéléyef proposed a process in 1892 for the preparation of nitro-cellulose, containing about 12·5 per cent. of azote, completely insoluble in alcohol, but soluble in a mixture of alcohol and ether without previously forming a gelatine. In a small quantity of the same mixture this substance, which Mendéléyef calls pyro-collodion, takes the form of jelly without dissolving. The composition of pyro-collodion is expressed by the formula  $C^{29}H^{38}(NO^2)^{12}O^{25}$ , which indicates a proportion of 12·44 per cent. of azote. It is therefore an intermediate substance between the collodions and cotton powder. The employment of pyro-collodions for the manufacture of powders, in which soluble nitro-cellulose must be used, should apparently give very good results. The military powder factory at Port Galère, St. Petersburg, uses pyro-collodion for smokeless powders for naval purposes. The chemist Eder has indicated a process for obtaining a nitro-cellulose containing nearly 12·75 per cent. of azote, but it is only a laboratory process.

The nitro-cellulose used in making smokeless powders is always in tufts or flocks, resembling tufts of wadding or of the cotton from which it is formed. Endeavours have been made for a long time to replace the cotton by other fibrous substances not so costly; thus in "Schultz"<sup>1</sup> powder wood bark treated with nitric acid was used as early as 1868. Different countries have carried out similar experiments with wood fibre, but as yet it has not been possible to obtain the necessary stability with these products. Improvements in the purification process of these ligneous fibres must nevertheless shortly cause a renewal of the researches in question. The nitrated cotton resembles ordinary cotton externally,

<sup>1</sup> Schultz powder is composed of nitro-lignite, nitrate of baryta, and nitrate of potash.



but is a little rougher to the touch; the colour varies from dark yellow to white according to the amount of washings in carbonate of ammonia solution. It is inodorous and insipid to taste when prepared with care. We have already seen that the solubility of the nitro-celluloses depends on the degree of nitrification; all however dissolve when they are subjected to a large excess of acetone. In nitro-glycerine the insoluble nitro-cellulose does not itself dissolve except in the presence of acetone. On the contrary, the collodions partly dissolve at normal temperatures, and completely at a temperature of  $50^{\circ}\text{C}$ . On this property Nobel has founded the preparation of his smokeless powders.

If imperfectly purified, cotton powder is a product very unstable and dangerous to handle; it is not the same with the cotton prepared by the Abel process, which may be kept for many years without spontaneous decomposition. Slow decomposition is produced, however, if the nitrated cotton is submitted to the action of solar light for many days, and results in the disengagement of nitrous vapours and the formation of traces of acetic, oxalic, and ferric acids and of glucose. Wet cotton powder (gun-cotton) is still more stable than dry. The chemist Hess has shown that wet cotton powder kept for a long time suffers alterations, which are revealed by the production of gummy masses, which cannot be separated by washings in water. The nitro-cotton powder does not contain sufficient oxygen to completely transform the carbon into carbonic acid; the result of this is that the products of decomposition comprise a notable quantity of carbonic oxide. When; therefore, we are obliged to employ powders containing nitro-cellulose in closed places, such as in casemates, due provision should be made by means of ventilation to prevent any injury which would be caused by the presence of such a deleterious gas as carbonic oxide.

*Nitro-Glycerine*.—Nitro-glycerine  $[\text{C}^3 \text{H}^5 \text{O}^3 (\text{NO}^2)^3]$  is obtained by pouring glycerine  $[\text{C}^3 \text{H}^3 (\text{OH})^3]$  into a mixture of nitric and concentrated sulphuric acid. The product is freed by washing from any trace of free acid. The use of nitro-glycerine as an explosive is due to the chemist Nobel, who, about 1868, originated the idea of mixing nitro-glycerine, considered up to that time as a very dangerous material, with an inert matter. He thus obtained dynamite, which offers much greater safety in management than nitro-glycerine. It was the same chemist who discovered later that nitro-cellulose and nitro-glycerine, which are such dangerous substances to handle separately, on the contrary, when mixed together form a product of very great security in management.

Nitro-glycerine is a very toxic, nearly colourless, oily liquid; prolonged contact of the liquid with the hands occasions headaches and syncope. It is insoluble in water, but dissolves in ether, benzine, and alcohol. In a state of purity it is very stable, and has been kept for twenty years without alteration. Very feeble traces of acid, however, suffice to make it detonate spontaneously, and heated to  $180^{\circ}\text{C}$ . it decomposes with explosion. It is much more sensitive to shock than nitro-cellulose. The quantity of oxygen enclosed by nitro-glycerine being

sufficient to transform all the carbon of the substance into carbonic acid, the explosion does not disengage carbonic oxide as is the case with nitro-cellulose.

*Preparation of Nobel Powders.*—At the commencement of the manufacture of Nobel powders, the process invented by Nobel himself was exclusively employed. Since 1890 the majority of the factories employ the Lundholm and Sayers process, which permits of a more simple method of mixing the nitro-glycerine and soluble nitro-cellulose. In the Nobel process a certain quantity of soluble nitro-cellulose at a temperature of  $6^{\circ}$  to  $8^{\circ}$  is treated with six to eight times its weight of nitro-glycerine. The operation is carried out in a special receptacle, from which the air is exhausted by an air pump. The bubbles of air which escape from the mass are replaced by the nitro-glycerine, which permeates the pores of the nitro-cellulose. The mixture thus obtained is then compressed in presses so as to squeeze out the excess of nitro-glycerine. The pressing is continued till the mass contains only one part of nitro-glycerine to one part of nitro-cellulose. The product is then broken up and heated to  $80^{\circ}$  in suitable pans. After a time, more or less extended according to the size of the fragments, the mass becomes plastic, becomes gelatinised, and the mixture of the substances being then intimate it is not possible to extract nitro-glycerine from it by compression. The gelatinous cake is then laminated by a laminating instrument, or by means of presses.

The Lundholm and Sayers process is that usually employed in the manufacture of Nobel powders. It is based on the fact that the mixture of the soluble nitro-cellulose with the nitro-glycerine is rendered much easier when the former substance is much attenuated with water. The nitro-cellulose and the nitro-glycerine are placed in a receptacle containing hot water, and the mixture is violently agitated by passing air or steam through the mass. When gelatinisation is produced the mass is first compressed so as to expel the greater part of the water, and then laminated between cylinders heated to  $50^{\circ}$  or  $60^{\circ}$ . The repeated laminations insure the expulsion of a certain quantity of moisture and the production of a compact and homogeneous cake; a part of the remaining moisture is eliminated by evaporation, the cylinders being maintained at a convenient temperature for the purpose. After lamination the cakes are granulated and then dried. During the operation of lamination, small explosions are sometimes heard; according to some writers they are due to the bursting of air bubbles in the mass. It seems more probable that they are particles of nitro-cellulose which cause the explosions, this substance being sensitive to shock and friction at a temperature of  $60^{\circ}$ . This supposition would also explain the presence in the mass of burnt portions of this substance. These explosions are quite local and not in any way dangerous. The Lundholm and Sayers process necessitates a desiccation of the powder, which was not required in the Nobel process. It can be effected either by prolonged exposure to the open air, or in stores maintained at a temperature not above  $40^{\circ}$ , so as to avoid evaporation of the nitro-glycerine.

*Preparation of Cordite.*—The process invented by Abel and Dewar consists in mixing insoluble nitro-cellulose with nitro-glycerine by the aid of a solvent, such as acetone. The cotton powder employed at the English factory at Waltham Abbey for this manufacture contains a minimum of 12.5° of azote. The mode of operation is as follows:—A mixture of nitro-cellulose previously dried and of nitro-glycerine weighing altogether about 34 kilogrammes is worked up carefully with the hands and then placed in a special mixing vessel, the bottom of which is hollowed out in the form of two half cylinders side by side, in section like the Greek letter  $\omega$ , with small propeller-shaped arms mounted in the axis of each half. These small propellers work in opposite directions, and the speed of revolution of one of them is half that of the other. Each portion of the mixture passes alternately from one cylinder to the other whilst being triturated by the arms, and the difference in the speed of rotation in the arms insures the successive kneading of all parts of the mass. The mixture is cooled during the operation by a current of water circulating in the space formed by the double sides of the box. In order to charge the mixer, the cover is raised, the nitro-glycerine and nitro-cellulose mixture is put in, and acetone poured into it in the proportion of one-fifth by weight; the cover is then hermetically closed to prevent the evaporation of the acetone. The first milling process lasts  $3\frac{1}{2}$  hours, vaseline is then added and the process is continued another  $3\frac{1}{2}$  hours. The apparatus is then inclined and the paste emptied into a wooden box lined internally with copper sheeting. This paste is then compressed by hydraulic presses in order to give it more consistency, and to expel the air bubbles. The last operation consists in moulding the powder into the form of cord in presses specially constructed for the purpose. 'Except for the dimensions,' the presses employed for small-arm powder are identical with those for big gun powder. In the first the charge for the press is 1 lb. English, and in the second 5 lbs. Small-arm powders when issuing from the presses are rolled on metal drums where they are allowed to dry for three days so as to eliminate any trace of the solvent. When the cartridges are filled, the cord thus obtained is cut by mechanical means to the requisite lengths. The charges are not regulated by weight, but by measuring the lengths, which is more convenient. As regards cordite for heavy guns, which is of greater thickness, they are cut into bundles of a predetermined length immediately on issuing from the presses. The duration of the drying process depends on the thickness of the powder, and is about eight days for powder destined for guns of medium calibre.

*Installation of Nitro-Glycerine Powder Factory.*—As we have seen, the manufacture of a nitro-glycerine powder is a very delicate and trying operation, both from the point of view of safety in the manipulation and in the quality of the product obtained, necessitating great purity in the original materials. It is then a matter of primary importance that these materials should be manufactured, or at least purified in the establishment where they are employed, so that their composition may be guaranteed. Every powder factory for nitro-glycerine powders

should therefore comprise in the works :—1. The manufacture or purification of the chemical products indispensable for the process: sulphuric acid, nitric acid, glycerine, etc. 2. The preparation of the nitro-celluloses, and the nitro-glycerine. We give below, as example, some description of a factory for Nobel powders at Avigliano, in Italy, one of the best organised in Europe. The Nobel factory of Avigliano was founded in 1872 by a group of Italian and Swiss capitalists, united under the name of the Nobel Dynamite Company, and was at first limited to the production of dynamite, but little by little the manufacture developed and extended so as to include all the new explosives. Since 1889 it has produced the smokeless powders of the Nobel type known as ballistite or filite. The factory is situated 25 kilometres west of Turin, on the right bank of the Dora Riparia, close to the village of Avigliano. It occupies an area of 209,000 square metres, and is surrounded by a continuous wall more than 3 kilometres in length. The establishment numbers 314 roomy buildings connected by a network of railways, and a principal one which joins the main line between Turin and Modane, at the Avigliano station, about 1 kilometre from the works.

Nearly all the chemical products required for the manufacture of the explosives are made at the factory. The shops for the preparation of these products are situated on the plain, whilst those for the production and storage of the explosives are installed on the adjacent hill. These last are light barracks, separated by large spaces, and communication between them is by small passages or covered ways. The establishment is divided into three sections, each sub-divided into a number of offices or workshops.—*First section*: Motive apparatus, water, compressed air, lighting, repairing shops for machinery, works department. *Second section*: The manufacture of chemical products. *Third section*: The manufacture of the explosives.

*First Section*.—The total H.P. of the motive apparatus is 700, and it is sufficient to work all the machinery of the establishment simultaneously. The power is supplied partly by means of four compound engines, yielding 560-H.P., and 13 steam generators; and partly by four Girard turbines yielding 140-H.P., driven by water from a large canal. Advantage will shortly be taken in these factories of the progress made in recent years in the transmission of power at a distance. There has already been secured 100-H.P. furnished by the Electric Company of Upper Italy, who are at the present time utilising a fall of the Dora Riparia for the distribution of motive power in the whole of the Susa Valley. The necessary water for boilers, washing machines, fire service, drinking purposes, etc., is drawn from the canal of Avigliano by five pumps equal together to the delivery of 216,000 litres per hour, into a large reservoir placed at a height of 34 metres.

Five air compressors, capable of compressing 192 cubic metres to a pressure of five atmospheres per hour, serve to work 37 ammunition hoists for the purpose of transporting the chemical products from the chemical works to the powder factories. The shops are lighted entirely by electricity by 580 incandescent 16-candle-power lamps, and

3 arc lamps of 1,500-candle-power fed by 3 dynamos. There are 24 shops for the repair of machinery.

*Second Section.*—In this section the necessary chemicals are prepared for the powder; the secondary products and residues are sold to the trade. 1. The sulphuric acid is obtained from the pyrites supplied from the mines of Chialamberto; this mineral, very rich in sulphur and copper, is free from arsenic, and yields a very pure acid much appreciated commercially. The works produce 20,000 kilogrammes of acid per day. 2. The nitric acid is obtained from nitrate of soda, obtained direct from Chili. The installation at Avigliano for the preparation of nitric (azotic) acid is the most important in Europe; it turns out 11,000 kilogrammes of highly concentrated acid per day, used only for explosives, and 13,000 kilogrammes of less concentrated acid, a great part of which is sold to the trade. 3. The glycerine is supplied in a crude state from different firms in Italy, and is subjected to distillation at Avigliano in order to purify and concentrate it. The refiners of the establishment turn out 3,000 kilogrammes of chemically pure and concentrated glycerine every 24 hours. The greater part of this is used in the preparation of nitro-glycerine; the rest is sold. 4. Sulphate of soda and hydrochloric acid are produced for sale, permitting of the use of the great quantity of bisulphate resulting from the manufacture of the nitric acid. 5. The excess of sulphuric acid, which arises when there is an interruption in the manufacture of some explosive, is used in the preparation of superphosphates, which are largely exported abroad. 6. The firm also utilises the copper of the pyrites for the production of sulphate of copper. Finally, amongst other secondary products, of which the yield is intermittent, depending on the demands of trade, are sulphates of iron and of manganese, nitrates of lead and of ammonia, bisulphate of soda, etc.

*Third Section. 1. Manufacture of Nitro-Glycerine and Dynamite.*—The nitrification of the glycerine by means of concentrated sulphuric and nitric acids is carried out in two large apparatus provided with refrigerators and agitators. The nitro-glycerine, which floats on the surface of the mixture, is decanted and submitted to repeated washings. In this way, after some hours of work, 3,000 kilogrammes of nitro-glycerine are produced per day. A part of this substance is transformed into dynamite; the other part is used in the manufacture of smokeless powder.

*2. Manufacture of Nitro-Cellulose.*—The washed cotton, which constitutes the original material, is at first submitted to a series of operations in order to dry it completely. The nitrification is effected by a mixture of nitric and sulphuric acid in 16 movable barrels. The nitro-cellulose is afterwards placed in 6 turbines, and subjected to a drying process, in order to extract the greater part of the acid mixture; it is then repeatedly washed and pounded till the cellulose is transformed into a very fine paste. This operation is performed by means of 12 pulping machines. The purification and desiccation of the paste thus obtained is done in a special apparatus, of which the firm possesses the patent; it is then ready

for the manufacture of the smokeless powder. The establishment can turn out 2,600 kilogrammes of this nitro-cellulose daily.

3. *Cotton Powder*.—This is prepared in a similar way to the nitro-cellulose, but the paste is transformed under great pressure into a white substance easy to work. In the two preceding manufactures powerful aspirators absorb the nitrous fumes which are generated in the apparatus and the presence of which would be dangerous to the health of the workmen. The Nobel factories at Avigliano are fitted to produce 4,000 kilogrammes of smokeless powder daily. The samples are submitted to very minute analysis and trials before being issued to the Service for war purposes. So important and excellently arranged as this establishment is, it yet suffers from one great defect, that it is so close to the frontier and, consequently, not safe from capture by a *coup de main* at the commencement of a campaign. In 1890, therefore, the Italian Government decided to found a military powder factory at Fontana-Lire, in the centre of the country between Rome and Naples, for the manufacture of smokeless powder. This establishment commenced work in 1893, and manufactures the chemical and other original materials for the preparation of this description of powder, but as regards this speciality is only a miniature Avigliano

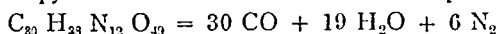
#### THE PYRO-COLLODION POWDER OF THE RUSSIAN NAVY.

By G. MAQUIN, *Capitaine d'Artillerie*.

Professor Mendéléyef, a Russian chemist of very high repute, was deputed by the Russian Admiralty, in 1890, to visit the principal smokeless powder factories in London and Paris, with a view to subsequent experiments in this direction. The result of his enquiries led him to the conclusion that existing powders, owing to different influences during their manufacture, were wanting in uniformity in their qualities. In this state of affairs, one of the first points to which the professor directed his attention was in the composition and production of collodion. He was thus led to the conviction that there existed many species of collodion; as the result of experiments in this substance he discovered a means of obtaining, by varying the ordinary means of procedure, a particular collodion intermediate between gun-cotton (or pyroxyle) and ordinary collodion as regards the quantity of azote it contained, and to which for this reason he gave the name of pyro-collodion. The proportion of azote (nitric acid) for pyroxyle is 13 per cent, pyro-collodion 12·5 per cent., collodion 11·5 per cent. Insoluble in alcohol, this pyro-collodion is soluble in a mixture of alcohol and ether and will gelatinise in it when the quantity of the solvent is small. It can then be made into ribbons or sheets which, when dried, have the appearance of celluloid; it detonates in a closed vessel without residue. It is this substance, of a well-defined nature and composition, which is the base of the new smokeless powder actually employed in the Russian Navy, and the manufacture of which is, at present, a secret. If the formula of the penta-collodion of Eder is  $C_{12}H_{13}(NO^2)_{12}O_{13}$ , that of pyro-collodion will be  $C_{33}H_{23}(NO^2)_{12}O_{25}$ , and 100 parts of dry cellulose will give 169·4 parts of the first product

and 166.7 of the second. We believe that the fact of having for a base a well-defined body, that is to say, having always an identical chemical composition, is a very important one in powder manufacture. The regularity of the results, the constant velocities and pressures with equal charges, their progressive variation as the charge varies, are, in fact, the best qualities that can be obtained when the powder remains the same in composition. Now gun-cotton powders cannot possess these qualities in a very high degree, because they contain very often products of inferior nitrification besides the celluloses; from this fact, to obtain results more or less regular with this powder we are obliged to have recourse to mechanical mixture.

*Volume of Gas Evolved by Deflagration.*—We know that in accordance with the law of Avogadro and Gerhardt it is possible, knowing the complete formulæ of deflagration of a body of which the products of combustion are in the form of gas or vapour, to calculate the relative volume occupied by these products at a given temperature and pressure. In the case of pyro-collodion the formula of decomposition is:—



$$\text{Weight} = 30 \times 28 + 19 \times 18 + 6 \times 28 = 1,350$$

$$\text{Volume of Gas} = 30 \times 2 + 19 \times 2 + 6 \times 2 = 110$$

Whence it results that for 1,350 parts by weight we have 110 by volume. For 1,000 in weight we then have 81.5 in volume, which is expressed thus:  $V \ 1,000 = 81.5$ .

This value V is superior to that corresponding to the most highly nitrated smokeless powder, whether of gun-cotton or nitro-glycerine. It surpasses very considerably that for black powder, which is only equal to about 30. [Here the editor of the *Revue* points out that the volume of gas evolved per kilogramme is maximum not for pyro-collodion but for the minimum nitrification within the limits, which will assure the combustion of the carbon. From this point of view tetra-nitrated cotton would be superior both to pyro-collodion and the penta-nitrated cotton powder of the Navy; but, on the other hand, taking account of the heat disengaged, we recognise that the most nitrated products yield the maximum forces and the most advantageous ballistic properties. We see, however, that the question is much more complex than indicated by the author.]

*Degree of Stability.*—Pyro-collodion keeps very well. When washed in water under proper conditions it can be heated to 65° C. without suffering alteration (as proved by Abel), not only for 10 to 20 minutes as ordinary gun-cotton, but for hours at a time if the washing in water has been followed by washing in alcohol. As to powder having pyro-collodion as a base, it can be heated to 110° as with the best gun-cotton. With a powder of which the pyro-collodion has been well washed this temperature of 110° has been maintained for 8 hours without any trace of redness on litmus paper. It was decided that the first trials of the pyro-collodion powder should be made in Q.F. guns of 47 millimetres and in the 7.62-millimetre rifle. The trials were therefore commenced by

means of shells furnished with crusher gauges in order to determine the thickness which should be given to the laminæ to reproduce the conditions of force corresponding to that of ordinary powder in guns of these calibres. Flakes of larger dimensions were afterwards tried, and showed that it was easy to regulate the dimension so as to vary the duration of combustion (or more exactly the time required for crushing the gauge) from  $\frac{1}{1000}$  to  $\frac{1}{80}$  of a second. These trials also brought out prominently the fact that the growth in the duration of combustion was almost exactly proportional to that of the thickness of the laminæ. Now we know that in the other smokeless powders this quality is not so notable, and it is precisely for this reason that the employment of these powders for heavy guns has been so restricted, from the difficulty of finding powders of sufficiently slow combustion. The fact of being able to modify the force of explosion by a simple alteration in the dimensions of the grain of powder employed, and without the addition of any retarding substance, is one of the essential characteristics of the new substance, and opens the possibility of its appropriation for guns of the largest calibre.

The following table shows the results of experiments which have been made by the technical laboratory of the Russian Admiralty by Mr. Smirnoff, and which form the superiority of the new powder. All these results correspond to pressures above 2,000 atmospheres. The charges employed were:—

Gun-cotton	-	44 grains.	2 density of charge.
Pyro-collodion	44	"	2 " " "
Nitro-glycerine	40	"	1.8 " " "

If D be the duration of combustion, that is the time during which the gauge is compressed, and E the thickness of the powder grains, the following table shows that pyro-collodion powder burns slower than the other smokeless powders:—

Pyro-collodion.		—	Nitro-glycerine powder.	Pyro-collodion.	—	Gun-cotton powder.	Pyro-collodion (calculated).
E	D	E	D	D	E	D	D
	Millionths of second.		Millionths of second.	Millionths of second.		Millionths of second.	Millionths of second.
Millimetres.		Millimetres.			Millimetres.		
0.09	1.2 to 1.5	0.8	2 <sup>1</sup>	1.9	0.7	2.7	4.4
0.65 to 0.72	4.0 to 6.1	1.0	2 <sup>2</sup>	6.0 <sup>1</sup>	1.4	7.0	8.1
2.06	11.4 <sup>1</sup>	1.6	3 <sup>1</sup>	9.1			
14.00	45.0 <sup>1</sup>	3.0	6 <sup>1</sup>	16.0 <sup>1</sup>			
		5.0	13 <sup>1</sup>	26.0 <sup>1</sup>			
		5.4	12 <sup>1</sup>	27.7			

<sup>1</sup> Approximately.

A comparative study more or less complete was also made of the products of combustion of the different powders. It was proved that



smokeless powders often give evidence of imperfect combustion in their products. For example, in analysing cordite we find:—

Nitro-glycerine	-	·57	per cent.	Carbon	-	23·3	per cent.
Gun-cotton	-	29·07	„	Hydrogen	-	3·06	„
Collodion	-	8·15	„	Oxygen	-	58·2	„
Carb.-hydrogen	-	5·1	„	Nitric acid	-	15·1	„
Ashes	-	·34	„	Ashes	-	·34	„
Moisture	-	·34	„				

Now in cordite in order for all the hydrogen to be converted into water and all the carbon into carbonic oxide 55·5 per cent. of oxygen is necessary, and in order for the hydrogen to be converted into water and all the carbon into carbonic acid 84·8 per cent. of oxygen is required. As cordite only contains 58·2 per cent. of oxygen, it is plain that there must be incomplete combustion in the products, and this experiment has proved.

In the case of ballistite also the product has not enough oxygen for complete combustion. To transform the H and C into water and CO, 52·2 per cent. of oxygen is required and for transformation into water and CO<sup>2</sup> 81·4 per cent., whilst ballistite only contains 59·6 per cent. of oxygen. The same can be shown with respect to pyro-collodion.

At the time of these first trials in 1892, laboratory experiments showed that no smokeless powder then in use was entirely satisfactory. Since that time improvements have been sought both from the side of gun-cotton as of the nitro-glycerine powders. But time pressed; further there already existed in Russia gun-cotton powder establishments for arms of small calibres, which was used both in the Army and Navy and for torpedoes. It was therefore decided to continue the studies with a view to improvement in these powders. That this was a fortunate decision Professor Mendéléyef's remark to-day proves:—"There has," he says, "been no discovery since 1892 which has eliminated the defects of nitro-glycerine powders, particularly from the point of view of the erosion to which it gives rise."

*Velocities and Pressures.*—If  $V$  be the initial velocity impressed by a powder charge  $\pi$  to a projectile of weight  $p$  for a pressure  $P$ , the author estimates that  $\frac{V}{P}$  is one of the most important quantities to consider in the comparison of different powders. Further, he says, the greater this value the more advantageous are the ballistic properties, for with equal pressure we get a higher initial velocity. From the point of view of economy it is the live force of the projectile per unit of weight of powder  $\frac{p}{\pi} \frac{V^2}{2}$ , which plays the principal rôle, for it gives us some idea of the expenditure necessary to obtain a certain effect; this quantity is designated hereafter  $F$ . Each of these two values corresponds to different qualities of the powder, and we shall have on multiplying them together  $R = \frac{p}{P} \frac{V^3}{\pi}$ , which in a condensed form gives us an approximate idea of the combined qualities of the powder.

The comparative results of the best gun-cotton powder, and of pyro-collodion with grains of .25 millimetre thickness and a density of 1.621, in the 7.62-millimetre rifle of length of barrel of 805 millimetres and a weight of bullet of 13.77 grammes are:—

Powder.	$\pi$ Grammes.	P Atmospheres.	V Metres.	$\frac{V}{P}$	F	R	$\frac{V}{\pi}$
Gun-cotton ...	2.38	2500	625	.250	$226 \times 10^4$	$56 \times 10^4$	262
Pyro-collodion {	2.3	2081	622	.298	$231 \times 10^4$	$69 \times 10^4$	270
	2.4	2103	637	.306	$232 \times 10^4$	$70 \times 10^4$	265
	2.5	2352	652	.276	$233 \times 10^4$	$65 \times 10^4$	260

The last column gives the relation of the initial velocity to the weight of the charge. If all the powder is really burnt in the barrel, this quantity decreases while the charge is increased. On the whole the numbers in the table are in favour of the pyro-collodion powder in particular that it gives the velocities for a less pressure. Experiments were carried out in the 3-pounder 47-millimetre Q.F. gun, the details of which were as follows:—

Length in calibres -	43.57	Weight of projectile	1.506 kilos.
Capacity of chamber	.845 litre	Weight of charge -	717 grammes.
Initial velocity -	600 metres	Pressure - -	2,030 atmos.
		Pressure admissible	2,500 „

The experiments commenced in May, 1892, and were continued in 1893. As already mentioned, the thickness of the laminæ had been determined by experiment so as to give approximately the same velocities as the brown powder in use. Three thicknesses were employed successively, six shots with the thinnest, twenty-four with the medium, and seven with the thickest laminæ. The projectile weighed exactly 1.497 kilogrammes. The results obtained are exhibited in the accompanying table, from which it will be seen that as the laminæ increase in thickness  $\frac{V}{P}$  increases but F decreases. From a ballistic point of view therefore thick laminæ are to be chosen, whilst from the economical one thin ones are preferable. Practically the choice depends on which of these two conditions predominates.

*Experiments with the 3-pounder Gun.*

No. of rounds.	$\pi$ Grammes.	P Atmospheres.	V Metres.	$\frac{V}{P}$	F	R	$\frac{V}{\pi}$
<i>With Thin Laminæ.</i>							
1	341	2045	697	.340	$213 \times 10^4$	$72 \times 10^4$	8.72
1	345	2080	700	.338	$213 \times 10^4$	$72 \times 10^4$	8.65
4	350	2147	705	.337	$213 \times 10^4$	$70 \times 10^4$	8.60

*Experiments with the 3-pounder Gun—contd.**With Medium Laminæ.*

1	291	1810	638	·352	$191 \times 10^4$	$67 \times 10^4$	8·50
2 <sup>1</sup>	341	1945	665	·338	$191 \times 10^4$	$66 \times 10^4$	8·31 <sup>1</sup>
2	350	1935	691	·347	$205 \times 10^4$	$71 \times 10^4$	8·41
2	354	2028	699	·342	$205 \times 10^4$	$70 \times 10^4$	8·41
4 <sup>1</sup>	358	2012	700	·347	$205 \times 10^4$	$71 \times 10^4$	8·31 <sup>1</sup>
8	367	2025	710	·349	$206 \times 10^4$	$72 \times 10^4$	8·26
2	375	2110	720	·340	$208 \times 10^4$	$71 \times 10^4$	8·17

*With Thick Laminæ.*

1	213	<1500	470	—			
1 <sup>1</sup>	277	<1500	518	—			
2 <sup>1</sup>	341	1580	621	·393	$170 \times 10^4$	$67 \times 10^4$	7·77
3	311	1745	642	·366	$181 \times 10^4$	$66 \times 10^4$	8·02

<sup>1</sup> The powder in these cases was not completely dry, it still contained traces of the solvent.

If it be wished to determine the necessary thickness of laminæ to give a velocity the highest possible without exceeding a pressure of 2,100 atmospheres all consideration as to the weight of the charge may be disregarded. The pressure of 2,100 atmospheres corresponds with the thinnest laminæ to  $V = 701$  metres and  $\pi = 350$  grammes. With the medium thickness  $V = 716$  metres and  $\pi = 370$  grammes, the thicker laminæ of the two are therefore to be selected. The results of other experiments made with the laminæ of greatest thickness showed that the pressure of 2,100 atmospheres corresponded to about  $V = 762$  metres and  $\pi = 400$  grammes. We could, therefore, increase the thickness chosen, but in this case we should have to increase the capacity of the powder chamber. If this were done it would appear that velocities of 800 in weight be obtained without exceeding a pressure of 2,300 atmospheres. Similar experiments were carried out with 37<sup>1</sup>-millimetre, 152<sup>1</sup>-millimetre, 228<sup>1</sup>-millimetre, and 304<sup>1</sup>-millimetre guns, and the manufacture of pyro-collodion powder was begun on a large scale in 1893.

The later experiments date from the commencement of 1894, and they have been followed by others in 1895 and 1896, when the manufacture of the pyro-collodion powder was perfected. Unfortunately the results of these trials has not been published by Professor Mendéléyef. According to *Engineering*, on the trials of some plates which took place at Okhta towards the end of 1895, the mean velocity on impact of 6 rounds with the 152-millimetre gun with projectiles weighing 39·5 kilogrammes was 786 metres. Two exceptional rounds give velocities of 864 and 878 metres. The normal velocity at the muzzle actually fixed for this gun was 792 metres. In November, 1896, a gun of 203 millimetres, 45 calibres in length, completely pierced a Krupp plate of hardened steel 25 metre thick; the velocity of the projectile was 868 metres on impact, and 213 metres

<sup>1</sup> The tabular results given in the original have been omitted in the translation, as they are all of similar character.

on the other side of the plate. About the same time experiments were projected, in which it would be attempted to pierce a Krupp plate 364 metre thick, with a 250-millimetre projectile weighing 225 kilogrammes, having an impact velocity of 864 metres. The result is not known. The table gives the initial velocities of the principal guns used in the Russian Navy with pyro-collodion powder.

Calibre. Millimetres.	Length in Calibres.	Weight of projectile. Kilogrammes.	Muzzle velocity. Metres.
301	40	322	838
250	45	225	822
120	45	20.4	792
75	45	4.9	853
47	45	1.5	701

Such are the important results obtained by Professor Mendéléyef's pyro-collodion powder.