

A detailed Review on the Military Powders Production in Germany during WWI and an Overview on British, American and Russian WWI challenges

1. Military powders production in Germany during WWI

1.1 Preface

The blockage on the Central Empires was employed in full, after the entrance of Romania to WWI on the Alliance (or Agreement) side on August 28, 1916. The question became clearly that of raw materials, and especially those manufactured from edible agricultural materials. In this respect, powders manufacturing caused a most acute problem, since nitroglycerine and alcohol were produced from edible materials. Duchemin ¹ writes that during the entire War, the powder manufacture problem was the “bottle neck” in Germany of the ammunition industry. Citation of the original passage:

“ ..les difficultés du ravitaillement en munitions tinrent beaucoup plus à la fabrication des explosifs et surtout des poudres qu’à l’usinage des obus. Pendant toute la guerre, les Empires centraux durent subordonner leur production de munitions à leur possibilité de fabrication de poudres.”

Jeffery Johnson similarly remarks that the blockade induced the need for local mobilization of the chemical industry and that powder supply was the bottleneck in Germany and Austria for the first three years of the war. ²

1.2 German WWI production data

The data given by Duchemin (*ibid*) for the German monthly programs of 1915, 1916 (two different values were given in the same reference for 1916) and for 1917, is presented in the table below. It is compared to the French parallel average monthly consumption, calculated by averaging the yearly powder supplied to the French military-See pages 228-237 for French wartime yearly supplies to the military. The

¹ Duchemin , Poudres et Explosifs 1914-1918 (Suite et fin)’, Revue Militaire Française, 52,(Octobre 1925), p.98.

² Jeffery Allan Johnson, “Technological Mobilization and Muniton Production: Comparative Perspectives on Gemrny and Austria”, in Frontline and Factory. ..pp.3,9

similarities in values on the two sides in 1916 and 1917, point to similar powder needs, leading to similar efforts in scale-up.

Table 36-Average monthly wartime powder supplies in Germany and France

Year	Germany	France	Notes
1915	6000 (tons per month)	3350	J.Johnson gives similar magnitudes: 10,000 tons obtained by Dec. 1917 and 12000, by Autumn 1918 ³
1916	Two values were given: 8000, 10000	10380	
1917	12000	12700	

Although the Germans produced double base Ballistite, RPC/12 and Cordite, which required less volatile solvents or none at all, the amount of single base produced was large enough to require large amounts of solvents and to preoccupy the German side on this issue as well. According to Duchemin⁴, the 1916 monthly powder program of 10000 tons called for the monthly production of **85000** hectoliters of alcohol. The parallel French consumption at that year was **120000** hectoliters per month, as calculated from Duchemin who gives the French daily alcohol consumption for 1916 as **4000** hectoliters per day. Calculating this per months, gives some **120000** hectoliters.

1.3 German WWI production changes

1.3.1 Preface

The efforts on the German side were typified by the development of raw material processes relying on more abundant materials in Germany, especially those that could replace edible materials. Such were the efforts to produce nitric acid, which could not rely anymore on Chilean nitrate as its raw material, as before. Nitric acid was essential, both to the manufacture of nitrocellulose, nitroglycerine and for the explosive industries. Cellulose, an essential material for nitrocellulose was produced successfully from wood and not from cotton, which was a scarce commodity. Glycerin, a key raw material for nitroglycerine, was obtained from candle and soap processes, which consumed animal and vegetable fats. Lack of these fats led to food

³ Ibid., pp. 13,14

⁴ Duchemin , "Poudres et Explosifs 1914-1918 (Suite et fin)" , Revue Militaire Française, 52, (Octobre 1925), p104.

shortages and nitroglycerine shortages for Ballistite and RPC/12. The manufacture of glycerine from sugar, a more common material in Germany, reduced this shortage.

1.3.2 The question of RPC/12 contribution to German war efforts

Johnson indicates that solventless nitroglycerine based powders were produced by the Duneberg plant. These were produced for large calibers. Duneberg manufactured some 75% of all nitroglycerine based powders and belonged to the Rottweil group. The solventless process (RPC/12) developed before the war greatly accelerated production because of the large reduction of drying times and by saving in acetone. As gathered from Johnson, the contribution was felt only in the first part of the war. In late 1916, military production increased sharply following the ambitious Hindenburg program. Since quotas were not met, nitrocellulose was replaced by inferior materials⁵. Kinder writes that the acute food shortages due to the manufacture of nitroglycerine from sugar in 1917, led to 300,000 thousand deaths in Germany in 1917. This provoked enormous social and political tensions⁶. Thus, in the sense of using less nitrocellulose, RPC/12 did not relieve that nitrocellulose shortage. In the sense of using nitroglycerine, it only increased the problem. Urbanski⁷ attributes a much clearer and important role of the RPC/12 powder, developed in 1912, to the protracted resistance of the Central powers: “The powder was used extensively during World War I since it could be produced much more quickly than CP powder. The manufacture of this powder contributed largely to the long resistance of the Central Powers... The rapid manufacture of RPC/12 powder was one of the reasons for the protracted resistance of the Central Powers during World War I. The lack of acetone suffered by the Central powers at the time had no effect on the production capacity of the German factories.. The manufacture of this powder was kept a secret and not disclosed until after World War I.”. Urbanski also notes a new RPC/12 specific phase, the “ripening” period: The paste obtained by mixing nitrocellulose and water slurry with nitroglycerine was left to “ripe” for two weeks before being processed in

⁵ Jeffery Allan Johnson, “Technological Mobilization and Munition Production: Comparative Perspectives on Germany and Austria”, in Frontline and Factory. ..pp.9,14

⁶ Sebastian Kinder, “Transforming the village into an industrial town”, in Frontline and Factory. ..pp.50,59

⁷ Tadeusz Urbanski, Chemistry and Technology of Explosives, Vol.III, pp.530,652.

the next step of calendaring or “hot-rolling”. This next step turned the paste into plasticized and brittle, nitrocellulose-nitroglycerine sheets. Since the percentage of nitroglycerine was some 25% and not 40% as in Ballistite, the paste obtained was not well “gelatinized”. The “ripening” was needed to allow the liquid nitroglycerin to partially diffuse throughout the nitrocellulose and to equalize in its percentages⁸. The ripening phase of some two weeks was obviously not found in the solvent-based processes, as poudre B or in Cordite. Urbanski refers to a later “modern” improvement, which eliminated the need of “ripening”. The exact date of the upgrade was not given. However, Urbanski’s description of the WWII process still includes one week of ripening⁹. The original references used by Urbanski for the description of RPC/12 WWI process and strategic advantages were not found to be cited in Urbanski’s works .

Muraour 1923 study resembles Urbanski’s enthusiasm with RPC/12. Muraour as Urbanski estimated that Germany would have been in a very critical situation without this discovery, since it would have found itself in an impossible situation of supplying such an enormous quantity of acetone and faced with long durations of drying. He also noted that the only inconvenience in the process was that the production was not without danger, and led to spontaneous inflammations in the hot rolls and also to explosion of presses, which required special precautions¹⁰.

The technical details provided by Muraour, with the additions of Urbanski on ripening, induce several questions, which seem to limit the RPC/12 advantages, pointing to the possibility that its disadvantages outweighed the advantages on the macro scale:

According to Muraour, double base types of powders, were chosen by the navy some few years before WWI, in place of single base powders, since they provided higher exit velocities for the same maximal pressure. The double-based powders contained some 25-30% nitroglycerine, and produced with the help of acetone, as in the British Cordite. This was manufactured until 1912 when the Duneberg powder plant succeeded in the manufacture of RPC/12, containing 25% nitroglycerine, produced

⁸ Ibid., p.653.

⁹ Ibid., p.662

¹⁰ Henri Muraour, “Note sur les différent types de poudres utilisés en Allemagne avant et pendant la guerre”, p.507.

without solvents. The powder was developed for navy large caliber calibers but the navy soon adopted the RPC/12 for small calibers. RPC/12 was also manufactured for army 420 mm howitzers, probably because its tubular shape allowed for better ignition and because its composition was less erosive than the standard Ballistite type. When war erupted ¹¹ most of the stocks were still the old Cordite. Muraour addresses the wartime production of RPC/12, including its intended use, in two places in his report:

1) In the summary part of the report, Muraour presents in brief, the types of powders, which were manufactures in WWI. The RPC/12 was indicated as being manufactured in WWI and was labeled as “the standard powder in the navy since 1912”. This is in agreement with Muraour’s prewar description of RPC/12’s intended use¹². The switch back to Cordite type powders was described as performed to thin powders of the navy, for safety reason.

2) In the middle part of his report, Muraour ¹³ provides the same information, although with a less precisely. He writes about “Wartime production of powders for large calibers”. (See original citation at the end of this page 263). The content of the passage however, indicates that Muraour was not referring to all large calibers, but only to navy large and small calibers powders. He writes in that the Duneberg plant intensified its RPC/12 production, as the hostilities broke out. He also notes that due to explosions risks, the Duneberg plant went back to produce the thinner powders for small caliber guns (which require shorter periods of drying) with acetone, as in the old German Cordite process. The drying time for thinner powders was relatively short, and probably did not warrant the advantage of RPC/12 short drying duration. Since only powders for small navy calibers were produced with RPC/12 before WWI, Muraour most probably refers to thin powders for small navy calibers. It seems plausible that Muraour implies that given the fact that thinner navy powders were no longer produced with RPC/12, what remained for large (navy) calibers was RPC/12.

The reasons for the strategic importance of the RPC/12 in Muraour’s report seem contradictory: He estimated that Germany would have been in a very critical situation

¹¹ Ibid., pp 505-507.

¹² Ibid., pp. 506-508.

¹³ Henri Muraour, “Note sur les différent types de poudres utilisés en Allemagne avant et pendant la guerre”, p.509

without this discovery, since it would have found itself in an impossible situation of supplying such an enormous quantity of acetone and faced with long durations of drying. (The saving in drying time may have been some 6 days, the time needed to dry Cordite types. It certainly was not two weeks or more, the time required for the thick tubular German navy single base powders, whose use was terminated few years before WWI. However, Muraour does not refer to the “ripening” period of two weeks as addressed by Urbanski, which offsets the advantage in the elimination of the drying duration. The advantage in acetone consumption reduction may not have been very critical: Muraour refers to the partial switch back to acetone -see paragraph above. This may indicate that Duneberg was not in critical position with acetone. In addition the manufacture of acetone prior to WWI was performed from wood and not edible materials as ether and alcohol- see pages 274,275 for British wartime efforts). Citation of the original passage: ¹⁴

“Poudres pour canons des gros calibres – Des le début des hostilités, la poudrerie de Duneberg intensifia la fabrication des poudres sans dissolvant. On peut dire que sans la découverte de ces poudres l’Allemagne se serait trouvée dans une position extrêmement critique car il ne pouvait être question, en temps de guerre, de préparer des poudres à l’acétone nécessitant des séchages très prolonges, d’ailleurs l’Allemagne aurait été dans l’impossibilité de se procurer les quantités énormes d’acétone nécessaire pour ses fabrications.

En vue de remédier à la pénurie de nitroglycérine, Duneberg étudia la substitution partielle a ce produit du trinitrotoluène a bas point de fusion (poudre trotyl). L’augmentation croissante des livraisons de glycérine synthétique amena l’arrête de la fabrication des poudres de ce type.

Duneberg a également fabrique pendant la guerre une certaine quantité de poudres tubulaires avec dissolvant. Il s’agit probablement de poudres de faible épaisseur pour de petit calibre. Le séchage pour ces poudres est relativement rapide et l’addition d’acétone diminue beaucoup les dangers de fabrication.”

¹⁴ Ibid., p.509.

Muraour also refers to wartime replacements of Ballistite for mortars and howitzers by single base powders, due to the nitroglycerine shortage¹⁵. The Germans were thus re-manufacturing the older nitrocellulose base powders to resolve the nitroglycerine problem, being able to pay, in the use of solvents as ether-alcohol and nitrocellulose. It may point out, as the German Cordite process for thin navy powders, to a lesser acute solvent shortage.

During the shortage in nitroglycerine, Duneberg substituted part of the material with TNT in the RPC/12, leading to a less energetic powder. This method was dropped once the shortage of nitroglycerine was resolved. This points to one basic problem with all nitroglycerine based powders, the need to modify compositions in wartime. A replacement of materials in peacetime requires lengthy proof tests for stability and ballistics. In wartime, the rapid changes to TNT was certainly a burden to developers and lead to probable compromises. Muraour and Urbanski in the specific references cited in this section did not examine these possible disadvantages. Nor was the strategic advantage/disadvantage of using nitrocellulose powders in place of RPC/12 assessed since nitrocellulose as replacements in other double base German powders were being used.

Two citations from Muraour's report indicate that the SDP was aware during WWI about the RPC/12:

1) Muraour¹⁶ examines the prewar reasons for the replacements of navy single base powders for large calibers with double base. The Germans explained that thick single base powders required prolonged soaking "*trempage*" (hot water immersion to soak out the solvents). This led to reduced gelatinization on the surface, leading to a faster burning rate on the surface, and to an anti-progressive burning. The new double base powders, which did not require prolonged drying, were the solution. The comparative test results showed a clear superiority for the double base powders. (Muraour provides no comparative information on the energetic differences and geometric differences

¹⁵ Henri Muraour, "Note sur les différent types de poudres utilisés en Allemagne avant et pendant la guerre", p.509.

¹⁶ Ibid., p.506.

between the single base and the double base powders, two factors, in increase of velocities).

Muraour concluded that the German claim above was true from a study conducted in a manometric bomb by the LCP with a double base powder taken from a German gun, which bombarded Dunkirk. (He does not say if this was a double base of the RPC/12 solvent-less type or German double base of the Cordite type. But in later part of the report, see in paragraph No 2 below page 266 below, Muraour refers to a wartime manometric bomb study by the LCP for erosivity of captured solvent-less powder. It seems that Muraour refers there to the same study and powder). The studies conducted showed that the German powders were clearly more progressive than the French poudre B powders for large calibers. (One reason for the superiority may have been the fact that poudre B is ribbon shaped while that of the RPC/12 was tubular in shaped, and thus inherently more progressive, although by a moderate difference). Citation of the original passage:

“Les poudres dans la Marine- la marine allemande avait adopté pour ces canons les poudres à la nitroglycérine. Il est intéressant de rechercher l’origine de cette adoption.

D’après les renseignements qu’il nous a été possible de nous procurer, des essais comparatifs effectués de nombreuses années avant la guerre dans des canons de différents types auraient monter pour les canons de gros calibres, une supériorité nette des poudres à la nitroglycérine, à pression égale les vitesses obtenues étant sensiblement supérieures. Les Allemands ont donné de cette raison de cette supériorité la raison suivante: Le dissolvant des poudres épaisses à la nitrocellulose ne s’élimine qu’après des trempages prolongés, ces trempages produiraient une dégéletasinisation partielle de la surface des brins de poudre, d’où l’obtention d’une poudre anti-progressive, les couches superficielles ayant une vivacité de combustion plus grande que le centre. Ces conclusions sont en accord avec les résultats que nous avons obtenus au Laboratoire central des poudres dans l’étude des poudres allemandes. Les traces obtenues à la bombe dans des essais comparatifs exécutés d’une part avec la poudre du canon allemand ayant bombarde Dunkerque, d’autre part avec des poudres épaisses a la nitrocellulose, ayant montre, au point de vue progressivité, une supériorité très nette des poudres du premier type.”

2) Muraour, in another part of the report ¹⁷, notes that German solvent-less powders for large calibers were examined in the LCP during the war for erosivity. The flame temperature of the German powder was similar to that of poudre B. (This is a logical consequence of the relative small differences in energies between RPC/12 and poudre B-see page 23 for comparative table of powders energies. In addition, the German powder for smaller calibers guns had a higher temperature than the solvent-less for large caliber. (This may be a consequence to the fact that the smaller navy guns were manufactured with higher energy—the old Cordite, although Muraour does not specify if the powders were sampled from German navy gun powders). Citation of the original passage:

“En ce qui concerne le pouvoir érosif des poudres sans dissolvant, l'étude que nous avons effectuée au Laboratoire central des poudres a montré que la température d'explosion des poudres sans dissolvant pour canons de gros calibres était plus basse, que la température d'explosions de poudre pour canons de petits calibres. En outre ces températures d'explosion sont en tous points comparables aux températures d'explosion des poudres françaises correspondants. Le pouvoir érosif des deux types des poudres peut donc être considéré comme identique.”

The SDP was thus most probably aware of RPC/12 performance characteristics. It may have not been aware of the actual solvent-less process activities in Duneberg, but the main details of the process were very probably known because of Claessens prewar patents and British prewar examinations. (See pages 166-169 for pre war powder developments in Germany and Britain concerning RPC/12).

1.3.3 Raw materials process changes and comparable French efforts

1.3.3.1 Preface

The German efforts on key wartime raw materials presented below, demonstrate an advanced prewar technological capability, which could be mobilized to provide the necessary solutions in large-scale production. The French comparable efforts

¹⁷ Henri Muraour, “Note sur les différents types de poudres utilisés en Allemagne avant et pendant la guerre”, p.508.

demonstrated similar know-how (except for the Haber process which was not utilized at all). This know-how was implemented in “bench-scale” (small) processes, and was not required in general, to be proven, in large-scale production.

1.3.3.2 Cellulose for nitrocellulose

The prewar nitrocellulose production was based on cellulose from cotton, as in France. The Agreement side blockade on cotton became effective by April 1915, and began to be felt by September 1915. This came at the time of a sharp growth in the need for nitrocellulose for powders, besides the great needs of cotton for the textile industry. Kinder demonstrates the importance of nitrocellulose based powders, by giving comparable numbers of such powder vs double base, produced beginning January 1916 in the new wartime Royal Prussian Powder plant¹⁸). Research all through WWI was devoted to finding local plants, which could provide fibers for the textile industry. The nettle plants provided some positive results, as for the use of towels and tablecloth. This was not sufficient for nitrocellulose, which required cellulose not only analog in its physical character to cellulose from cotton, but having the chemical characteristics of cotton cellulose. This was found in the “wood paste” (“*pâte de bois*”) used in the paper industry. The feasibility of these particular materials in the nitrocellulose industry was already tested in Germany at the end of the previous century. The woods, which were needed, were very white pines, which were brought from the invaded territories of the east. By the end of WWI the powder plants employed only wood cellulose¹⁹. There was nevertheless a shortage in nitrocellulose during WWI, initiating a partial replacement of nitrocellulose in field gun powders with ammonium nitrate and wood carbon. This also indicated by Johnson²⁰.

The SDP tested replacements for cotton cellulose before WWI and more intensively during WWI. Recommendation in WWI was given for cotton cellulose replacements (as fir and bamboo trees) and for process changes to enable the use of such alternative cellulose. These studies were not put into practice because cotton was always

¹⁸ Sebastian Kinder, “Transforming the village into an industrial town”, in Frontline and Factory. ..pp.54,55

¹⁹ Duchemin, “Poudres et Explosifs 1914-1918” (Suite et fin), Revue Militaire Française, 52, (Octobre 1925,), pp.100-101.

²⁰ Jeffery Allan Johnson, “Technological Mobilization and Munition Production: Comparative Perspectives on Germany and Austria”, in Frontline and Factory. ..p.14

sufficient for use and for stockpiling. (See page 250, on French wartime efforts concerning nitrocellulose replacements).

1.3.3.3 Nitroglycerine

Before WWI glycerin was obtained as a by-product in the candles and soaps industries, which utilized for their processes, animal and vegetable fats. (This also indicated by Johnson²¹). Germany imported prior to WWI, some of 300,000 tons of animal fats each year, while 1,600,000 tons were produced in Germany. Vegetable fats were mostly imported from abroad, some 600,000 tons (as oil) per year. The industry (candles and soaps) used 450,000 tons per year and the rest was used in the food industry. The sudden blockade on imports created the wartime “office of oils and fats”. It brought down industry consumption to 50,000 tons, so fats could be reserved for food. Soaps began to contain some 90% of clay and in the German occupied territories after armistice regular soap was a much cherished commodity. The drastic reduction of soap and candle manufacture brought down the availability of glycerin, which was needed more than ever before for the growing needs of the powder industry. Glycerin was also needed for other military uses, as in guns (in the recoil mechanism), and as a coolant in machine guns. For such uses, physical homologues (having similar viscosities and boiling points) were used, based on salts of soda or potassium without any trace of glycerine.²²

The powder industry could not use physical homologues and the soaps and candles industry were required to improve processes and assure that all glycerine byproducts were recuperated. Research concentrated on the production of fats from different materials in Germany, as grains from fruits, and dead animals. But this did not satisfy the powder needs and an alternative process was invented, that of the manufacture of glycerine from sugar. This raw material was imported in large scale before WWI, and was an exception in the general shortage. The chemical ingenuity provided the powder industry with the needed nitroglycerine throughout WWI, but the population suffered a “fat” hunger as a result. Duchemin recalls that in first days of armistice in

²¹ Ibid. ..p.14

²² Duchemin, “Poudres et Explosifs 1914-1918” (Suite et fin), Revue Militaire Française, 52, (Octobre 1925,), pp.103-104.

occupied Rhine area, the patriotic pride of the local population was easily put aside for a piece of lard (“*saindoux*”).

The nitroglycerine problems described above support the argument in the Introduction section that the European experience proved that the prewar American decision not to use nitroglycerine was a correct. (See page 12 for the cited reference).

1.3.3.4 Alcohol-ether

Before WWI²³ alcohol was produced at a quantity of 3,700,000 hectoliters per year, of which 3,000,000 hectoliters were made from potatoes and 500,000 from grains. Potatoes growth was sharply reduced in WWI because fertilizers from Chile could not be imported anymore. The fertilizer was the same material needed for nitric acid for powders-“Chilean” saltpeter – NaNO_3 , a naturally found nitrate. The potatoes that could be grown were supplied to the population. The German occupation of northern France provided them with ample supply of beet and sugar allowing the production of alcohol from beet and sugar refineries residues. This was already performed in large scale in France before WWI. (See Table 29 on page 243). Nevertheless, beet was still needed as a feedstock for animals, and an initiative was undertaken to use a Swedish process introduced before WWI. This process consumed sugar from residual water exiting from the paper processes and the wood paste industry, which was increased in size to produce cellulose from woods. (See page 267 above). The sugar was turned to alcohol. There were key difficulties with the processes but the wood paste industries had to implement such processes.

The French, which also encountered alcohol shortages, were encouraging their distilleries to use all alcoholisable materials, as rice, corn, manioc, sugar residues, and wood sawdust. (See Table 29 on page 243).

Another effort undertaken was to create alcohol from acetylene. But this relied on producing large quantities of calcium carbide, which required ample and cheap electricity. This was not found in Germany but in Switzerland, where it was

²³ Duchemin, “Poudres et Explosifs 1914-1918” (Suite et fin), *Revue Militaire Française*, 52, (Octobre 1925), Suite et fin), p.103.

developed. Thus, the quantities produced in this process were low. Paul Pascal in wartime France was experimenting with such a possibility-see page 241.

The State also took control over alcohol to regulate uses, resembling the wartime alcohol monopoly in France.

The descriptions above point to the immense difficulties with alcohol shortages, and support the argument that the use of RPC/12 did not relieve the solvent problems in Germany.

1.3.3.5 Nitrates and nitric acid

Sodium nitrate (NaNO_3), Potassium nitrate (KNO_3) and lime (calcium) nitrate ($\text{Ca}(\text{NO}_3)_2$) were the major raw materials in the production of nitric acid, the major material in the production of powders and explosives in Germany.

Prior to WWI²⁴, Germany imported large quantities of nitrates for fertilizers (“Chilean” saltpeter – NaNO_3 which is a naturally found nitrate): 770,000 tons per year were imported from Chile in 1913. In addition, 50,000 tons of lime nitrates were imported from Norway, manufactured there in a synthetic process. Some 600,000 were allocated as fertilizers for agriculture. The blockade eliminated both fertilizers and foods imports, doubling the effect. At the same time the powder supply programs required immense tonnage of nitrates (the Hindenburg program of 1917 called for 12,000 tons of powders per months requiring 60,000 tons of nitrates, corresponding approximately to the monthly consumption of the agriculture). Thus, the demand increased by 100% but resources decreased by 90%. Certain prominent French chemists predicted that Germany would not hold on, as a result. But the German industry was involved prior to WWI in alternative processes for nitrates, which were scaled up in WWI. An English physicist Crookes stated the motive for the alternative processes in 1898, pointing to the possibility of hunger once the Chilean reserves would be depleted.

²⁴ Duchemin, “Poudres et Explosifs 1914-1918 (Suite et fin)”, *Revue Militaire Française*, 52, (Octobre 1925) pp.107-113

The nitric acid was obtained in wartime Germany from artificially prepared nitrates, through several processes:

- Nitric acid through electric arc: The earliest and most known process of the synthetic route. The “electric arc”, combined atmospheric gaseous nitrogen and oxygen by the intense heat produced by the electric arc. The process required ample and cheap supply of electricity, which was found in Norway and this process was highly developed in that country. The Norwegian Society of Nitrogen built in France such a plant in the Pyrénées in 1916, delivering 10 tons per day of nitric acid. (See page 253). In Germany, cheap electricity as in France, was not abundant and other processes were preferred based on the manufacture of ammonia NH_3 that provided the needed nitrogen in the nitric acid (HNO_3), in place of the natural nitrates (see below)
- Nitric acid obtained from the manufacture of ammonia (either through the Cyanamid process or Haber process), and then using it in the Ostwald process:

a) Ammonia (NH_3) from the Cyanamid process- this was obtained by heating lime (calcium) carbide in a stream of nitrogen gas. Cyanamid is obtained, which is then heated with water to obtain ammonia. The problem was in obtaining calcium carbide, which needed ample and cheap electricity. Despite the difficulty, the process was utilized in Germany before WWI and in 1916, passed 30,000 tons per month. Production diminished as the Haber process evolved into a more efficient one. Note that during WWI the Cyanamid process was also active in France. (See pages: 253-255).

b) Ammonia (NH_3) from the Haber process- the process consisted of obtaining ammonia, by producing hydrogen from water and reacting it with atmospheric oxygen at 500°C and pressure of 200 atmospheres. This process was not utilized in France. Its main difficulty was in obtaining the high pressures.

c) Using ammonia (from the Cyanamid or Haber processes) to obtain nitric acid-The Ostwald process:

The process consisted of two steps.

- a) Producing nitrous oxide (gas) by passing the NH₃ (ammonia) in catalytic combustion (on platinum)
- b) Absorption of nitrous oxide in water (in absorption columns) to form nitric acid

The German Ostwald process (beginning 1915) oxidized **30,000** tons of ammonia per month (the Angoulême site for comparison, was manufacturing only some **2,400** tons per month of nitric acid using the Ostwald process see pages: 253-255). The **30,000** tons of ammonia per month yielded by calculation some **48,000** tons of nitric acid per month. The comparative French nitric acid consumption (1917) was **60,000** tons per month (see page 253).

Jeffery Johnson gives the value of **36,000** tons of ammonia per month by April 1916.

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1.3.3.5 Pyrites and sulfuric acid

Before WWI²⁶, Germany imported the main raw material Pyrite from Spain, as France. After the blockade, this natural resource was queried in previously closed German mines and in new mines opened in Hungary and Turkey. To relieve imports, new processes were sought. One process used successfully, was the recovery of sulfur from oil distillation products. This method reduced the imports by half. The production in France continued to rely on Pyrites, which were imported with a certain degree of difficulties. (See page 255).

1.3.4 Powders production

The types of military powders produced in WWI, were summarized by Muraour²⁷:

²⁵ Jeffery Allan Johnson, "Technological Mobilization and Munition Production: Comparative Perspectives on Germany and Austria", in *Frontline and Factory*.. p.12.

²⁶ Duchemin, "Poudres et Explosifs 1914-1918"(Suite et fin), *Revue Militaire Française*, 52, (Octobre 1925), pp.106-107.

²⁷ Henri Muraour, "Note sur les différents types de poudres utilisés en Allemagne avant et pendant la guerre", p.511.

- **Nitrocellulose based powders (single base)** were used in WWI for small arms and field guns as in France. In order to save on nitrocellulose use, a mixture of ammonium nitrate and carbon was utilized to replace part of the nitrocellulose in field gun powders. This “ ammonpulver ” had the advantage of lower muzzle flash but was very hygroscopic.
- **Ballistite types were used for mortars and howitzers.** The shortage of nitroglycerine has often led to the replacement of Ballistite type with single base or the use of nitro-aromatic derivatives in place of nitroglycerine. These practices were used until the new synthetic glycerine process relieved the nitroglycerine shortage.
- **RCP/12** was manufactured for the navy and for 420 mm howitzer. Due to explosions risks, thinner powders for small navy caliber guns, which require shorter periods of drying, were manufactured with acetone, as in the old Cordite process. The shortage of nitroglycerine has often led to the replacement of nitroglycerine with TNT (the practice was used until the nitroglycerine shortage was relieved by the new synthetic glycerine process).

2. British, American and Russian WWI challenges

Britain –The acetone stocks for the standard composition at the beginning of WWI were low and supplies of renewed stock were uncertain. This was resolved by using a nitrocellulose type, which could be dissolved with a mixture of ether-alcohol and producing cordite “RDB”. Duchemin describes this development, ending his description in a flamboyant manner. Citation of the original passage: ²⁸

“la fabrication de la cordite “MD” nécessite de l’acétone. Les stocks de ce dissolvant étaient faibles, le ravitaillement incertain; la cordite “MD” fut remplacée par une cordite “RPB” à base de coton poudre soluble dont le dissolvant était le mélange éther-alcool. Le whisky remplaça l’acétone.”

Note that Duchemin labeled the modified composition as “RPB” but it was actually labeled as Cordite “RDB” an abbreviation for “Research Department B”. Acetone well dissolves the nitrocellulose with higher nitrogen content used in the MD. Using ether- alcohol in RDB, which does not satisfactorily dissolve nitrocellulose with higher nitrogen content, required as a consequence, the employment of nitrocellulose having less nitrogen percentage and less energy. This was compensated by increasing the nitroglycerine content from 30% in MD to 42%. The RDB was still slightly less energetic. After WWI, the manufacture of RDB was stopped because its ballistic properties were considered inferior. ^{29,30}

A successful attempt to alleviate the acetone shortage was undertaken by Weizman and Hamlyn who found a certain type of bacteria, which can produce acetone, when placed on potato or rice food platform. The Encyclopedia of Chemical Technology describes this innovation: “Until World War I, acetone was manufactured by the dry

²⁸ Duchemin, “Poudres et Explosifs 1914-1918”, (Suite et fin), Revue Militaire Française, 52, (Octobre 1925), .p.116.

²⁹ Encyclopedia of Explosives and related items, ed. Basil Fedoroff, 3, (Dover, 1960-1983), pp.C532-534.

³⁰ Tadeusz Urbanski, Chemistry and Technology of Explosives, Vol.III (Oxford, 1967), pp. 543,644.

distillation of calcium acetate, which was obtained by neutralizing pyroilgneous acid (wood distillate) with lime and evaporating to dryness. When World War I began new methods of manufacture were explored. Calcium acetate could be made from acetic acid, which had been produced by fermentation of alcohol or from acetylene. However, this method could not compete with the fermentation process developed by Weizman and Hamlyn. The conversion of carbohydrates, (cornstarch or molasses), to acetone and butyl and ethyl alcohol by use of special bacillus. This method became uncompetitive in the late 1950's and early 1960's." ³¹

It is apparent from the descriptions above that the Weizman and Hamlyn process provided an industrial scale solution in wartime Britain, but an additional solution was sought and implemented, that of RDB powder produced with ether and alcohol. This is further supported by Cocroft who described RDB as being allocated for the land services while the acetone based Cordite was reserved for the Navy. ³²

USA – “The need for powder during the First World War was immense. European requests rose from 1,500,000 pounds per month (some **23** metric tons per day) to 9,000,000 pounds per month (some **136** tons per day) at the time the U.S entered the War. Yet the (American) Ordinance program called for an additional 75,000,000 pounds (some **1133** tons per day), none of which could be obtained from sources of supplies developed for the Allies.

.. During World War I, Picatinny Arsenal was the first American producer of propellant powder for the United States Army (producing all sizes from 0.30 caliber to 16 inch), though the total amount manufactured was but a fraction of that produced throughout the United States by the end of the war. More important than powder production, was the role of the ordnance inspectors trained at Picatinny. These inspectors, working with independent contractors, supervised the construction of all the powder plants built during the war. In all, some 53 plants, at an estimated cost of \$360,000,000 were begun by the Ordnance department (and operated by civilian contractors) to supply explosives (both high and low explosives). A large part of this construction was completed and was in a surprisingly efficient state of operation by November 11, 1918.

³¹ Encyclopedia of chemical technology , ed. Kirk-Othmer, 1, p. 170,

³² Wayne D. Cockroft, “First World War Explosive Manufacture”, in Frontline and Factory. .p33

..Between April 1, 1917 and November 11, 1918, American smokeless powder factories produced 632,000,000 pounds, (**287,272** metric tons), equal to the combined production of France and Great Britain.”³³

Note that the author (Sandra Norman) most likely refers to the parallel production in France and Britain in the parallel time span April 1, 1917 and November 11, 1918, since the total French wartime production of powders alone was approximately **310,000** tons.

Russia- “Lieutenant Bernadou was in Petersburg as a military-naval attaché of the USA during the time Mendeleev was working on pyrocollodian powder. He often visited the Russian scientist’s laboratory, and despite measures to ensure secrecy managed to obtain full evidence relating to the composition of the powder and the methods of production, as was confirmed by his paper delivered to the American military and naval college in 1897. Pyrocollodian powder was produced in great quantities in America, especially during the First World War when tens of thousands of tons of it were sent to Russia where the powder industry was unable to produce the quantities required due to insufficient production capacity and the lack of chemical raw materials. Indeed during the entire World War the Russian Field Services were severely lacking smokeless powder, more than 60% of which was supplied by the USA, England, France and Japan on severely unfavorable terms”.³⁴

Part of the reasons for raw material shortages as Pyrites, was due to cessations of imports from Scandinavia.³⁵

³³ Sandra Lee Norman, Guncotton to smokeless power: the development of Nitrocellulose military explosive, 1845-1929, pp.154-155.

³⁴ Ivanovitch Ivan Vernidub, “One hundred years of the Russian Smokeless (nitrocellulose) Powder industry”, pp.395-400.

³⁵ Nathan M. Brooks, “Munitions. The Military, and chemistry in Russia”, in Frontline and Factory.
..p81

Ivanovitch Ivan Vernidub, “One hundred years of the Russian Smokeless (nitrocellulose) Powder industry”, pp.395-400.