ALFRED NOBEL: FROM GUNPOWDER TO BALLISTIT

Bertil Enoksson
Department of Physical Chemistry, Uppsala University, Uppsala, Sweden

ABSTRACT: Alfred Nobel was an inventor in many different fields who possessed a rare creative power. His scientific contributions were above all others in the explosives area with epoch-making results also of technical and economic importance: the introduction of high explosives, invention of the detonator, dynamite, blasting gelatin, gelatinous explosives, double base propellant, and progressive powder.

INTRODUCTION

Alfred Bernhard Nobel was born in Stockholm, Sweden, on 21 October 1833. He died at San Remo, Italy, on 10 December 1896.

During his lifetime, Alfred Nobel was honored in many ways, but he accepted few official distinctions and complained that none of his orders had any foundation in explosives. Nonetheless, he highly appreciated his membership in the Royal Academy of Sciences, Stockholm, and the honorary degree of Doctor of Philosophy, which he received in 1893 at the University of Uppsala.

It is obvious that Alfred Nobel wanted to be remembered foremost for his scientific contributions in the field of explosives. Therefore, to commemorate Alfred Nobel, I will recount the struggle in the explosives market among blackpowder, cellulose nitrate and glycerol trinitrate, emphasizing the contributions made by Alfred Nobel.

In his teenage years in St. Petersburg, Alfred Nobel got to know about explosives and their possibilities. His father, Immanuel Nobel, managed a foundry and wheel factory, where among many other items, he also manufactured land and sea mines. In 1850, Alfred Nobel was sent to study in Sweden, Prussia, France, and North America. He spent most of his time abroad in Paris studying chemistry, partly at the laboratory of the famous Jules Pelouze. Alfred Nobel became familiar with the science of the time and learned about esterification with nitric acid. This knowledge was to be of vital importance to his work with nitroglycerin.

When back in St.Petersburg in 1854, Alfred Nobel was employed by his father's company, Nobel et Fils, which prospered as a consequence of the large orders by the Russian state during the Crimean War. But when the war came to an end in 1856, the company soon became insolvent. Alfred was sent to bankers in London and Paris in search of a loan. No one was willing to grant credit to the Nobels. Immanuel Nobel was bankrupt, and in 1859 he returned to Stockholm. His three eldest sons, Robert, Ludvig, and Alfred, stayed in St. Petersburg, where they operated a small workshop.

BLACKPOWDER

Immanuel in Stockholm and Alfred Nobel in St. Petersburg, each individually, tried to find an explosive more effective than blackpowder. For more than 500 years, blackpowder had held its ground as the only propellant. Originally blackpowder consisted of approximately 40% saltpeter, 30% charcoal, and 30% sulphur, intimately ground together. Later normal gunpowder comprised 75% potassium nitrate, 15% charcoal and 10% sulphur, each component finely ground before moistened and mixed together.

If blackpowder is burned in a confined space, e.g., in a borehole, the pressure increases and so does the rate of burning to such a high value that it can be used for blasting. From the seventeenth century onward, blackpowder was applied to industrial blasting in mining. By varying the composition, granulation, and glazing, the blackpowder was adapted to the special use for which it was intended. Cheaper powder was produced in which potassium nitrate was replaced by sodium nitrate. Blackpowder slowly and only partly replaced the older fire-setting method, in which a fire was set against the rock face and then water was dashed onto the heated rocks. The broken rock could then be dug out.

Many additions were made to blackpowder in order to improve its properties. Other components were tested, but for a very long time blackpowder was the only explosive of importance on the market. No explosive has been or will be used for as many different applications as blackpowder. But times changed and blackpowder met a new threat from more specialized chemical agents and detonating explosives, such as nitrocellulose and nitroglycerin.

NITROCELLULOSE

Cellulose nitrate was the first serious rival to compete with blackpowder for the commercial explosive market. In 1845, Christian Friedrich Schönbein, professor of chemistry at Basel, discovered a way to produce nitrocellulose by immersing cotton or paper into a mixture of nitric and sulphuric acids. This invention was made during his research about ozone and "active oxygen." Schönbein immediately recognized the possibilities of the product obtained by esterification of cotton with nitric acid and patented it as guncotton. He expected that his guncotton would soon replace gunpowder as a propellant. However, the nitrated cotton was unstable. Disastrous explosive accidents occurred during the manufacture and storage of guncotton. Furthermore, the enormous pressure generated by firing guncotton charges damaged and sometimes even blew up the guns used. For this reason, the manufacture of guncotton was officially prohibited and the development was very much delayed.

NITROGLYCERIN

Soon, another high explosive appeared in the field. In 1846, Ascanio Sobrero, professor of industrial chemistry at Turin, discovered nitroglycerin. He slowly added glycerol to a pre-cooled mixture of nitric and sulphuric acids while stirring. When the reaction mixture was poured into water, nitroglycerin, an oil heavier than water, precipitated. It was purified by washing with a large amount of water.

Sobrero found nitroglycerin so unpredictable and frightening that he warned against its use. Although nitroglycerin showed its explosive strength, the danger seemed too great. It was only used in small quantities as a diluted alcoholic solution for a heart medicine.

It demanded a person with an extraordinary far-seeing spirit, ingenuity, courage, and an untiring energy to succeed in finding practical applications for this violent explosive. Alfred Nobel was that man.

NOBEL'S DETONATOR

Remarkably, the first main difficulty encountered with nitroglycerin was in detonation. A spark or contact with a flame caused it to burn calmly without detonating. Immanuel Nobel in Stockholm tried mixtures of blackpowder and nitroglycerin. He got a increase in the strength of blackpowder, but the inconveniences of both ingredients remained. Alfred Nobel in St. Petersburg started in the same way, but showed more creativity. He initiated nitroglycerin by a shock from an explosive charge smaller than the main blasting load. In its first form, this detonator consisted of gunpowder compressed in a wooden cylinder which was closed by two plugs. Into one of them a safety fuse with blackpowder had been inserted. Later, this led to a blasting cap with an initiating explosive which reacts violently when heated, such as mercury fulminate. This brilliant way to ignite high explosives to detonation was the first epoch-making invention by Alfred Nobel. It opened the era of high explosives in the blasting industry, from the heaving action of blackpowder at a low, sustained pressure causing minimum fragmentation, to the great possibilities of high explosives of widely different weight strength, detonation velocity and pressure, loading density and blasting action.

NOBEL'S BLASTING OIL

Alfred Nobel joined his father in Stockholm in 1863. Now, when he could initiate the detonation of nitroglycerin with unfailing certainty, he was ready to introduce nitroglycerin into blasting practice. His patented blasting oil was far superior in explosive power to ordinary gunpowder and had many advantages. Large savings in drilling labor and cost were achieved and the time required for much engineering work could be shortened tremendously. A growing demand for access to this effective explosive arose quickly. Military experts, however, declared that an explosive with such enormous strength was too dangerous to use in warfare.

The nitroglycerin was manufactured at the Nobels' pilot plant at Heleneborg in south Stockholm. Here, at the same time, work proceeded on improvements in the method of manufacturing nitroglycerin. On 3 September 1864, the temperature in the nitrating vessel rose out of control. A most terrible explosive accident followed, in which the whole factory was wiped out and five people were killed. Among the dead was Alfred Nobel's younger brother, Emil.

Now, there was no way back for Alfred Nobel. He had to show the world that his own faith in the usefulness and future of nitroglycerin was right. He needed to show that by his inventions, more people would be saved than lost by the introduction of high explosives into blasting techniques. This inspired him to do impressive, untiring work, in which he shrank from no difficulties for the betterment of mankind.

A ban was put on the manufacture and storage of nitroglycerin within populated areas. Alfred Nobel acted swiftly. Within a month after the accident, he was producing his blasting oil aboard a barge anchored on Lake Mälaren outside the bounds of Stockholm. In November 1864, Alfred Nobel founded his first limited company, Nitroglycerin AB. The following year, the company was granted a permit to build a nitroglycerin factory at a then-desolate creek of Mälaren, southwest of Stockholm .

DYNAMITE

At the start of his nitroglycerin business, Alfred Nobel was already fully aware of the disadvantages of the liquid form of the blasting oil. It led to accidents in transportation and use. The nitroglycerin ran into fissures in the rock and could cause explosions when the broken rock was picked out.

Alfred Nobel worked persistently to find a means to make nitroglycerin safer. At first, he tried to reduce the dangers by transporting nitroglycerin dissolved in methanol. However, this method proved to be inadequate, and Alfred Nobel found it necessary to add the blasting oil in another form. He turned his attention to adsorbing the nitroglycerin in fibrous or porous substances such as nitrocellulose, paper, charcoal, and sawdust. He decided on kieselguhr, a fine, porous deposit of cell walls of diatoms. Seventy-five percent nitroglycerin adsorbed in 25% calcined kieselguhr formed an easy-to-handle plastic explosive. Guhr dynamite was patented in 1867 and is the best known of Alfred Nobel's inventions.

The guhr dynamite aroused enormous interest all over the world in mining and communication industries. Alfred Nobel founded companies and built nitroglycerin and dynamite plants in many places in different countries. He wanted his explosives to be manufactured as near the place of consumption as possible. In 1865, Alfred Nobel moved to Hamburg and lived there until 1873, experimenting for safer and more efficient explosives at his laboratory at Krummel.

The nitroglycerin explosives made possible enterprises which had been unthought of with gunpowder. However, Alfred met unexpected competition from miners who used his blasting oil because they found guhr dynamite too weak, since it had only about 60% of the blasting effect of pure nitroglycerin. Nevertheless, the strength of dynamite was many times that of blackpowder.

More serious was the struggle with nitrocellulose, particularly in Britain. Guncotton with about 20% water was packed in the bore hole and initiated by a primer of dried, compressed nitrocellulose, which, ironically, was fired by a Nobel detonator.

To succeed, it was necessary to increase the strength of dynamite. As a step in this direction, in 1869 Alfred Nobel patented the use of active adsorbents, which in contrast to the heat-absorbing kieselguhr, contribute to explosive energy. Straight dynamite could comprise nitroglycerin adsorbed in wood pulp, sodium nitrate and, as a stabilizer, calcium carbonate. But Alfred Nobel was not satisfied. He wanted something really new, a very powerful explosive, safer to handle than guhr dynamite and resistant to water and moisture.

BLASTING GELATIN

In 1873, Alfred Nobel left Hamburg for Paris. He bought an elegant mansion on Avenue Malakoff and added a winter garden to his taste, stables for his horses, and a chemical laboratory for his research.

Alfred Nobel and his assistant, Georges Fehrenbach, made many tests with different explosive substitutes for kieselguhr, which was inert and also had the disadvantage of binding water better than nitroglycerin. From the outset they tried mixtures of nitroglycerin and nitrocellulose, but they got only suspensions of fibrous guncotton in the blasting oil and no coherent mass. Nitrocellulose adsorbs only small amounts of nitroglycerin. How to incorporate nitrocellulose with nitroglycerin and make nitrocellulose soluble in nitroglycerin? One day Alfred Nobel poured collodion, a solution of low-nitrogen nitrocellulose in ether-alcohol, into nitroglycerin. When most of the volatile solvents had evaporated, a rather stiff gel remained. His goal was within reach. However, many tests and much work had to be done before the invention was suited for presentation on the market. Only nitrocellulose with a nitrogen content of about 12.2% is directly soluble in nitroglycerin. With a 7 to 8% collodion nitrocotton in nitroglycerin, a tough, viscoelastic gel is formed in a few hours. This gel, blasting gelatin was patented in 1876.

A competitor to Alfred Nobel declared Nobel's blasting gelatin, in every respect, to be the most perfect explosive known. Blasting gelatin is slightly stronger than pure nitroglycerin, as the oxygen excess of the nitroglycerin is utilized by the nitrocellulose and gives an additional contribution to the explosive energy. By the detonation of 1 kg well confined blasting gelatin 6.5 MJ is released. In less than 1 ps the pressure at the detonation front rises to over 20 GPa and the temperature to about 5,000 K. The detonation velocity is near 8 km/s.

Blasting gelatin is a superior explosive, which was used for such demanding tasks as blasting the hardest rock and under-water blasting. But blasting gelatin was more important as the basis of the gelatinous explosives which rapidly came into wide use. With less nitrocellulose, a thinner and softer gelatin was obtained, in which mixtures of oxidizing agents and combustibles were incorporated. These plastic explosives could easily be packed in a bore hole and they also stayed in holes directed upwards. In addition, the gelatinous blasting explosives were cheaper and safer and still had a good resistance to water. Ammon gelatin, in which the oxidizer is ammonium nitrate, was patented by Alfred Nobel in 1879.

Nitroglycerin explosives, due to Alfred Nobel's inventions and research, became the choice of the civil blasting market. The properties of the gelatins and dynamites could be modified in many ways. It was even possible to develop explosives which, when fired in coal mines, did not ignite firedamp or coal dust. However, so far, nitroglycerin had little military importance, and blackpowder still controlled the propellant business.

BALLISTIT

The Nobel dynamite companies provided peaceful tools, not weapons. According to Alfred Nobel, blasting gelatin would propel not only the projectile, but also break the gun itself into fragments. Guncotton was tried as a propellant, but was unreliable. In spite of this, new lighter weapons were designed for more powerful propellants, which gave the bullet a much higher muzzle velocity than gunpowder could give. But the propellant with an easily controlled rate of burning was lacking.

While engaged in the development of blasting gelatin, Alfred Nobel began to think of a propellant consisting of nitroglycerin and nitrocellulose. His thoughts led him to celluloid, which has as two-thirds of its weight nitrocellulose and one-third camphor. Celluloid is too slow to propel projectiles and, besides, cannot burn without access to oxygen. Alfred Nobel thought that if the camphor was substituted partly or wholly with nitroglycerin, the burning rate would increase. The consistency would be retained, thus making it possible to form the powder in a proper way with a regulated surface and burning rate.

After many years of fundamental research and testing, Alfred Nobel finally introduced ballistit in 1888 It originally contained 60% nitrocellulose and 40% nitroglycerin and a small addition of diphenylamine as stabilizer. Ballistit was the first double base propellant. It produces great power and leaves no deposits and is nearly smokeless.

Ballistit was the last of the epoch-making discoveries by Alfred Nobel. It instantly aroused great interest. In scientific circles, Alfred Nobel's results were considered most remarkable and surprising. That two violent high explosives could combine into a propellant, which upon ignition burns with good stability and precision, was indeed impressive. It was also striking that ballistit could be rolled between hot rollers or pressed under heat into different shapes.

Alfred Nobel had once more shown how two competing chemical substances, nitrocellulose and nitroglycerin, can work together and take the market from the earlier dominating blackpowder. He was not so successful with people and governments. When they learned about the new smokeless powder, they feared that their weapons would become inferior to those of others. His laboratory at Sevran was closed by the French authorities, who would not tolerate any rivals to their own single base powder. Alfred Nobel left Paris in 1891 and settled down in San Remo, Italy. In the United Kingdom, ballistit had to compete with cordite, a nitroglycerin powder which was based on Alfred Nobel's own ideas and research. This was a very hard blow for Alfred Nobel personally and a loss of an enormous sum of money in royalties to him, and later on to the Nobel Foundation.

Alfred Nobel was very active with experiments, research, and development work in San Remo, Italy, and at Björkborn and Bofors, Sweden, until his death in 1896. His last discovery in the realm of explosives was progressive smokeless powder (Swedish patent in 1896). Thin sheets of more slowly burning powder were rolled or pressed on each side of a faster burning one.

EXPLOSIVE ENGRAVING OF ALFRED NOBEL

Alfred Nobel disliked all forms of personal attention and publicity. He wanted to be left in peace. Not even did he have his picture painted. How can I then dare to illustrate my lecture with a portrait of Alfred Nobel?

The metal plate for this picture of Alfred Nobel was produced by detonating a layer of explosive on a sheet of polymethyl methacrylate placed onto the painting on the plate. This explosive engraving method was developed by the artist Verner Molin in collaboration with Nitro Nobel, Alfred Nobel's first company. Thus this print has an explosive past and may be accepted in my lecture.

I will feel honored if this picture of Alfred Nobel could stay at this Symposium on Special Topics in Chemical Propulsion and later at the Workshop on Peaceful Utilization of Energetic Materials in St. Petersburg, where I hope it will remain.

REFERENCES

Bergengren, E., *Alfred Nobel: The Man and His Work*, Thomas Nelson and Sons, London, 1960.

Enoksson, B., The Cordite Case in View of Modern Physical Chemistry, *7th Symposium on Chemical Problems Connected with the Stability of Explosives,* ed. Hansson, J., Detonik och Förbränning, Sundbyberg, 1985, 1-17.

Enoksson, B., Gummidynamiten-Världens Första Explosiva Gelatin, *Svensk Kemisk Tidskrift-Kemiteknik,* Vol. 88, No. 12, 1976, 26-30.

Marshall, A., *Explosives: History and Manufacture, Vol. 1*, P. Blakistone's Son and Co., Philadelphia, 1917.

Miles, F.D., Cellulose Nitrate, *The Physical Chemistry of Cellulose Nitrate, its Formation and Use*, Oliver and Boyd, Edinburgh, 1955.

Naoum, P., Nitroglycerine and Nitroglycerine Explosives, *Baillière,* Tindall and Cox, London, 1928.

Nobel, A., *Improvements in the Manufacture of Explosives*, G.B. Patent No. 1471., 1888.

Reader, W.J., *Imperial Chemical Industries, A History, Vol. 1: The Forerunners*, Oxford University Press, London, 1970.

Romocki, S.J., Geschichte der Explosivstoffe II, *Die rauchschwachen Pulver in ihrer Entwickelung,* Robert Oppenheim, Berlin, 1896.
Schück, H. and Sohlman, R., *The Life of Alfred Nobel,* William Heinemann, London, 1926.
Storm, C.G., Smokeless Powder, *Colloid Chemixtry,* ed. Alexander, J., The Chemical Catalog Company, New York, 1932, 101-116.
Strandh, S., *Alfred Nobel.* Mannen, Verket, Samtiden, Natur och Kultur, Stockholm, 1983.
Widman, O., Det Gamla och Det Nya Krutet, *P.A. Norstedt och Söners Förlag,* Stockholm, 1899.

Explosive Engraving of Alfred B. Nobel
(Explosive Engraving Method Developed by Verner Molin, in collaboration with Nitro Nobel Co.)