Incident

The great explosion of 1916

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Summary

The main industrial uses of ammonium nitrate are in explosives and in agriculture as a high-nitrogen fertiliser. Many industrial accidents involving ammonium nitrate have been described in LPB; but this paper focuses on an industrial accident 100 years ago in the UK explosives industry. On 2 April 1916 a fire and explosion at a munitions factory on the Kent marshes killed 108 people, injured 97, and caused extensive on-site damage. The explosion was heard over 80km away. The initial fire and explosion involved ammonium nitrate and TNT. Domino effects affected other munitions all being prepared urgently for the war effort. The following description leans heavily on the sources listed in the bibliography.

Keywords: Explosion, explosives, domino effect

Introduction

Gunpowder, established in medieval times, remained the principle propellant for military purposes up to WW1. It comprises a mixture of carbon, sulphur and potassium nitrate. The Kent marshes proved an ideal location for the gunpowder industry because:

- The streams could be dammed at intervals to provide power for watermills;
- The land was well suited for growing alder and willow as a source of charcoal;
- The creek could be used for shipping in sulphur and transporting out finished product;
- Of the close proximity of the arsenals in London and the naval ports on the south coast from where it could be loaded for use or export.

As a result, the Home Works gunpowder mill was established at the head of Faversham creek in the 16th century. The Oare Works was developed towards the end of the 17th century and a third opened in 1787 known as the Marsh Works, built by the British government approximately 1km north-west of Faversham to augment output at its Home Works. This also had access to the sea via Oare Creek. The more dangerous operations were transferred from the Home Works to the Marsh works following an explosion.

The industry continued to expand and diversify. Guncotton (and its successors) were most suited to the Marsh plant since it was more remote from towns and was first manufactured under licence at the Marsh Works in 1847. Because the process was poorly understood a serious explosion resulted in 21 fatalities (only ten of whose bodies could be identified) and the factory subsequently shutdown. Guncotton was not made again in Faversham until 1873, when the Cotton Powder Company (CPC), independent of the gunpowder mills, opened on a remote virgin site about 4km northwest of the town centre alongside the Swale, a deep-water channel dividing mainland Kent from the Isle of Sheppey. Deliveries of raw materials (cotton waste and sulphuric and nitric acids) and despatch of guncotton could readily be made by water.

The explosives archipelago continued to develop and by the turn of the century, the CPC site at Uplees became one of the largest works in Britain producing 35 types of explosive. Cordite (a mixture of nitroglycerine and guncotton) soon became the main propellant for the British army and navy but the material proved somewhat uncontrollable. By the onset of the war, the main high-explosive used in British shells was based on picric acid (Lyddite) which was superseded by trinitrotoluene (TNT). In 1912, the Explosives Loading Company (ELC) joined the CPC at its western end specifically for filling shells with TNT (see Figure 1). The outbreak of WW1 created a vast, urgent demand for high explosives, met chiefly by the manufacture of amatol comprising 60% ammonium nitrate and 40% TNT, or 80% ammonium nitrate and 20% TNT mixtures. Since ammonium nitrate (AN) was cheaper than TNT its inclusion "stretched" the TNT and provided an internal source of oxygen. Following the "shell crisis" in 1915, the need for munitions became ever urgent and the Prime Minister established the Ministry of Munitions to control all explosives factories by coordination of production and distribution of munitions.

The Uplees site

The ELC plant was established in 1912 under an amending licence granted to the CPC to fill charges with TNT for shells, torpedoes, and mines. However, management also used Amatol. The entire site was complex with about 200 workers and comprising hundreds of buildings including processing plants, stores, offices, mess rooms, power houses, etc., the majority being of light construction. Most of the CPC factory was built on a floating crust above the marsh but magazines were on more solid ground built into the hill and screened by mounds. Buildings were linked by a tramway. The ELC was the smaller company with around 30 buildings, almost all of wooden construction with no mounds because each was separated from others by approximately 60m. Because of the explosion risk, the special safety arrangements reportedly included:

- No metal buttons were allowed on garments — buttons were all made of wood.

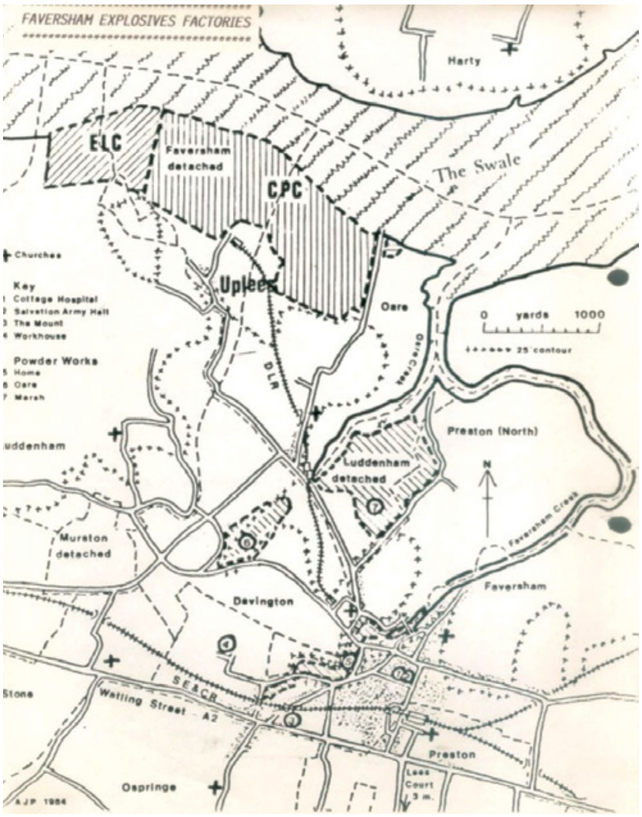

Figure 1 – Faversham explosives factories
ELC=Explosives Loading Company
CPC=Cotton Powder Company

- Women were not allowed metal hairpins or grips and had to have their hair tied up in a net.
- No pockets on overalls in which items could be kept were allowed.
- No pipes, matches or cigarettes were allowed into the works. These had to be put into pigeon holes by employees as they arrived for work.
- Tramway rails were made of wood close to buildings.
- Horses had brass horseshoes instead of steel to reduce the risk of sparks.
- Buildings were constructed of wood and well-spaced out. No metal nails were used.
- Security precautions included a military guard of 128 men and 24 patrolmen for the two factory sites. The CPC had its own part-time fire brigade, plenty of hydrants and hoses and a pump always at the ready to raise extra water. The ELC had only one four-man pump, 100 or so chemical extinguishers and a supply of fire buckets. Water was available from the dykes. High pressure mains water had been laid up to the factory and the hydrants were ready for installation but contractors had failed to deliver the pumps.

On 31 March 1916, H.M. Inspector of Explosives (Major Cooper-Key) undertook an unannounced inspection of ELC. In order to meet the nation's demand the Ministry of Munitions had stocked the factory with levels of raw materials far beyond the plant's production capabilities, despite complaints from management. About 40 tonnes of AN and 60 tonnes of TNT passed into the factory each week. Building No 833 contained stocks of AN plus 150 tonnes of TNT; an additional 50 tonnes load of TNT had recently been received for which there was no storage accommodation and it was therefore stacked in the open outside building 833. The TNT was packed in linen sacks inside the wooden crates. Empty AN barrels and TNT sacks had accumulated in spaces between offices, production units and boiler houses. He noted the absence of hydrants and fire buckets in various ELC buildings; the nearest fire-brigade was in Faversham. Nevertheless, the inspector concluded that he was satisfied with the general conditions, recognising the need for urgent production to meet government expectations.

The accident

Just after noon on Sunday 2 April 1916 it was noticed that some empty linen sacks leaning against the matchboard wall of building 833 had ignited. The alarm was raised immediately and the assistant manager took charge and attempted to extinguish the fire. Men with buckets formed a chain to the nearest dyke but the action proved futile and the building was well alight when the manager arrived. Problems were encountered in gathering sufficient fire hoses across the site to reach ELC buildings from CPC hydrants, and firefighters were unable to approach the buildings because of the intense heat. Three Faversham fire brigades turned out but were unable to reach the site in a timely manner through the narrow country lanes. Building 833 became a lost cause and the men agreed to move cases of TNT to a safe distance in an attempt to prevent fire escalation to other buildings including the CPC cordite plant. They tried to remove cases from within the building but were prevented by smoke and so concentrated on crates lying around three sides of the outside walls. The building was burning fiercely and the bulk of AN was alight. Fire trucks inflamed 35m away and sparks spread to other buildings. During the fire when a fire officer asked the deputy plant manager if there was any danger that the store of AN and TNT could explode he was reassured that it would only burn. For over an hour water was poured over the fire to no avail and the manager gave the order for everyone to evacuate. At 14:20, during the evacuation, the contents of building 833 detonated, followed immediately by explosion of the washing/filtering houses of the nitroglycerine plant, 110m away. Explosions of two further buildings followed. Five buildings were destroyed without trace, leaving behind craters some 10m wide and 4 – 6m deep (see Figure 2). All buildings of light construction within a radius of 200m of the epicentre of the initial fire were demolished and in total over 25 buildings belonging to the ELC were destroyed. The extent of the destruction is illustrated by examples shown in Figure 3. The human toll amounted to 108 deaths (including the entire works fire brigade) and 97 injuries. As the explosion occurred on a Sunday, no women were at work. The bodies of seven victims were never found and 70 of the corpses were buried in a mass grave at Faversham Cemetery on 6 April with the Archbishop of Canterbury in attendance. Letters of sympathy were received from the King and Queen.

The explosion was heard across the Thames estuary and as far away as Norwich and Great Yarmouth. In Southend-on-Sea, domestic windows and two large plate-glass shop windows were broken. This was the British explosives industry's worst industrial accident: others around this time included the

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explosion at the Barnbow shell-filling factory in Leeds on 5th Dec 1916 which resulted in 35 women losing their lives and many injuries.

Investigation

A few days after his unannounced inspection of ELC, Major Cooper-Key returned to the site this time to investigate the accident. His report puts the casualties at the time as 106, of whom 20 were CPC employees and four were military guards. Another source suggests all but five victims (who were members of the military) were employees helping with the emergency, or spectators, despite being warned to leave. The inspector confirmed the location of the initial explosion and suggested possible sources of ignition as cigarettes, sabotage, spontaneous ignition, or sparks from the powerhouse chimney. After giving reasons for dismissing the first three, he concluded that sparks were the most likely source. The three flues from the powerhouse were each fitted with a spark-catcher but they were of dubious efficiency and the wind was blowing almost directly from the boiler house towards the heap of bags just 15m away. Also, on the night before the accident, two patrolmen reported extinguishing a fire from this source between the boiler house and TNT store.

The report focussed on the vast quantity of stocks on site and concluded that had the store contained only TNT as per the licence, it was likely the contents would have simply melted and burned. However the amount of combined TNT and AN was equivalent to 75 tonnes of high explosive. (A further 3000 tonnes of explosive apparently remained in unaffected sheds after the accident suggesting the outcome could have been even more catastrophic).

In terms of accountability, the inspector acknowledged that management could not be completely exonerated from blame but he was clearly sympathetic of their plight. Thus:

- In permitting high levels of hazardous materials on site management were aware of the danger and had complained, but were over-ridden by government officials. (The inspector himself had raised the matter of congestion several times with the Ministry but given the necessity of immense scale of manufacture it was practically impossible to maintain the orderliness and method considered so essential in normal times);
- In departure from the conditions of the license he agreed that rapidity of output was the first priority and that it was extremely difficult, if not impossible, to strictly adhere to the exact letter of the licence.
- The inspector suggests it was government officials who either failed to recognise the risk of storing AN and TNT in the same building or had considered the risk justified by the urgency of national requirements.
- Attempts to fight the fire and move stocks from the scene could have put lives at risk, but the inspector singled out the manager and works manager for bravery including their success in extinguishing fires on the roof of the magazine containing 25 tonnes of TNT, thereby preventing another explosion, which would have taken out the cordite plant. (An inquest acquitted the managers of all blame).

Because of stocks of similar ingredients elsewhere in the UK the inspector had tests performed to ascertain whether TNT and AN together in unmixed states posed greater explosion risk than premixed amatol. Results, however, were inconclusive probably because of the inadequacy of the test facilities.

The inquest recommended more efficient appliances be installed in explosives factories but the inspector's report emphasised the difficulties of laying high-pressure water mains during war and although this had not been done at the present sites, it was due to no lack of effort by management. As a substitute, he recommended a four-man manual pump supplemented by fire-buckets and over 100 chemical fire extinguishers.

Lessons learned

The Minister of Munitions set up a standing committee to establish the causes of explosions in Government and controlled munitions factories. In May 1916, they issued a "secret" report making the following eight recommendations:

- Boiler-houses should be located as far as possible from danger buildings;
- Plenty of buckets filled with water should always be available in all buildings, and proper fire hydrants provided where possible;
- Part-time works fire brigades to be formed and trained by qualified firemen in use of various appliances at their disposal;
- Accumulations of empty boxes, bags, refuse of any flammable substances to be forbidden;
- Stocks of explosives or their ingredients for which proper storage was unavailable but which had to be stored on site should be placed as far away as possible from other buildings;
- TNT and AN must never be stored together in the same building;
- All conditions and terms of licences to be strictly adhered to, and
- If prompt use of fire buckets or hydrants fails to extinguish a fire at once then everyone should be withdrawn to a safe distance.

Nowadays, additional recommendations may be expected in terms of organisational considerations (for example, the appointment of the Ministry of Munitions represented a significant top-down organisational change which impacted the risk), management responsibilities, training staff in hazards, plant design (including boiler-houses, stores), process safety from cradle to grave, minimising inventory of hazardous materials, review of legislation, access for emergency services, etc. The fire on the night before the accident was a near-miss and was a lost opportunity to recognise the risk posed and thereby possibly circumvent the accident. Indeed, current day requirements are for zero tolerance to even the most minor fire within major hazard facilities.

Conclusion

This tragic but fascinating case study illustrates the difficulty of using hindsight to criticise human factors at times of war.

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The heroic attempts to dowse the fire and salvage explosives may be considered foolhardy nowadays, but the mentality to fight to save the plant could be linked to the workers' national pride in their contribution towards the war effort. Indeed, Lord Kitchener (The Secretary of State for War) wrote to the company's management in 1914 instructing the workforce on "the importance of the government work upon which they (were) engaged". "I should like all engaged by your company to know that it is fully recognised that they, in carrying out the great work of supplying munitions of war, are doing their duty for their King and Country, equally with those who have joined the Army for active service in the field." The inspector's report on the accident concluded that those who died at their posts gave their lives for their country in the fullest sense in trying to save a national disaster. Nevertheless, in the present case, this act is also attributable to lack of training, preparedness and provision of adequate equipment.

It is appreciated that under war conditions, time may not allow careful process development. However, one lesson highlighted by this accident is the need to fully understand the physical, chemical and hazardous properties of materials being used or formed, and of the processes adopted during manufacture. All involved should then be trained to appreciate these under normal and emergency conditions. At the time of the accident the physical and physiochemical properties of AN were poorly understood, which raised problems with its handling, storage, and the preparation of the various mixtures with nitro explosives, and on dealing with fires and explosions (as illustrated by the wrong advice given by the deputy plant manager to a fire officer). This is pivotal to the accident.

In mainland Europe, AN tended to be incorporated into nitro explosives at or below 40% when the nitro compound could be melted and mixed with dried AN to form a slurry which was poured into shells. In the UK, however, when blending higher concentrations of the cheaper AN component, problems were encountered in forming homogenous mixtures and in the storage and handling of bulk quantities. Large masses of AN could set rock-like and crates frequently had to be broken-up with pickaxes. This was eventually overcome by shipping the salt containing small quantities of water with subsequent drying in situ at the filling factories. It was also crucial for the shell contents to be above a minimum density so as to ensure complete and effective detonation, achieved by use of hydraulic presses to compact the mass by means of rams. This hazardous operation was housed in a separate building surrounded by mounds to minimise the effects of possible explosion, and the control levers and recording instrument were operated from outside the building. Mixtures filled into shells in a hot state tended to contract on cooling and recede from the immediate neighbourhood of the detonator and primer so that the fuse became ineffective. This was overcome by redesign of the shell and modification to the method of filling and inserting the fuse.

Whether risk assessments should result in higher levels of acceptable risk during wartime is a debatable topic. Production targets were driven by survival and military success rather than solely financial profit. In general the level of risk accepted by military personnel tends to be higher than that acceptable to civilian operators, and the rank of the chief inspector and that of some employees may suggest a military culture within the industry.

Today, where the number of inspectors allow, they should be rotated on a regular basis to avoid "regulatory capture" by management due to over-familiarity. Also, it would be wise to use a different inspector to investigate a significant accident than the person providing a routine regulatory service.

Material properties

TNT

TNT, manufactured by the (usually two-stage) nitration of toluene with a mixture of fuming nitric and sulphuric acids, is a relatively expensive explosive. It is an oxygen deficient explosive to which oxygen-rich substances (such as AN) are added to enhance its explosive power and it is one of the more stable high explosives. When pure the product is a colourless crystalline solid at room temperature melting at 81°C and boiling at 240°C. It detonates around its boiling point but can be distilled safely under reduced pressure. It may also detonate when subjected to strong shock. Small, unconfined quantities will burn quietly but sudden heating of any quantity may cause it to detonate.

TNT may enter the body via ingestion or inhalation of dust or fume but the main route of concern is by skin absorption. Target organs include the blood, liver, nerves and muscles. AN is hygroscopic and keeps the skin moist and as a result assists the passage of TNT through the skin thereby making amatol more dangerous than TNT alone. Over-exposure may result in a range of adverse health effects including skin irritation, cyanosis, atrophy of the liver, anaemia, muscular pains, menstrual irregularities etc. and, for some workers, the materials turned their hair, face, hands, forearm and legs orange/yellow from jaundice earning the ladies the name 'canary girls'. (This was also seen in WW2 but was less prevalent due to improved occupational hygiene controls).

Ammonium nitrate

Ammonium nitrate is manufactured by the exothermic reaction between ammonia gas and concentrated nitric acid

$$NH_3\text{ (gas)} + HNO_3\text{ (liquid)} = NH_4NO_3\text{ (solid)}$$

Ammonium nitrate is a white crystalline solid freely soluble in water when it absorbs tremendous amounts of heat. On heating it transforms between its many crystalline forms and melts.

$$\text{Tetragonal} \overset{-17^{\circ}C}{\leftrightarrow} \text{Rhombic 1} \overset{32.1^{\circ}C}{\leftrightarrow} \text{Rhombic 2}$$

$$\overset{84.2^{\circ}C}{\leftrightarrow} \text{Rhombohedral} \overset{125.2^{\circ}C}{\leftrightarrow} \text{Cubic} \overset{169.6^{\circ}C}{\leftrightarrow} \text{Liquid}$$

At 185–220°C it decomposes to nitrous oxide and water vapour; the decomposition becomes violent at 250°C

$$NH_4NO_3 = 2H_20 + N_2O$$

Nitrous oxide

Nitrous oxide is a colourless gas, stable at ordinary temperatures. However, above 600°C, it decomposes to oxygen and nitrogen and so supports combustion of burning substances just as vigorously as does oxygen. Whether this had any influence on the Faversham accident is unknown.

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Figure 2 – Crater created by explosion of building 217 (note man in centre)

Figure 3 – Remains of building 844

Pure AN may be locally heated to red heat without explosion and the decomposition does not spread. It may, however, explode violently on contact with flames or other ignition sources and can be induced to decompose explosively by detonation. Whilst pure AN is stable under "normal conditions" and can be stored in bulk, stockpiles pose a fire hazard due to its highly-oxidising properties, for example, when in contact with hydrocarbons such as oils. Since commercial AN often contains 1% hydrocarbon oil or 5% kaolin to prevent crystals sticking together these mixtures decompose explosively when heated locally and the explosion may spread throughout the entire mass.

Cordite

Cordite is manufactured by the nitration of purified, dry, cotton waste and the product ('nitro-cellulose' or 'guncotton') thoroughly washed before working into a uniform very loose state and pumped as a slurry and pressed to afford material of 50% water content (dried nitro-cellulose is dangerous to store and easily ignites and explodes). When ready to use, dried material is mixed with nitroglycerine into a paste to which mineral jelly and solvent are added and worked up to dough and extruded through orifices to form spaghetti-like cord known as Cordite. Dried product contains 65% nitro-cellulose, 30% nitroglycerine and 5% mineral jelly.

Postscript

Both Swale-side factories closed permanently in 1919. However, in 1924 a new venture, the Mining Explosives Company, opened a factory on the east side of Faversham Creek, not far from the site of Faversham Abbey — hence 'Abbey Works'. After a fatal accident in 1939, the proprietors abandoned the manufacture of high explosives to concentrate on making an explosive-substitute based on a reusable steel cartridge filled with carbon dioxide. The premises continued to be licensed under the 1875 Explosives Act, as gunpowder was used in the initiator. Manufacture continues today under the name Long Airdox.

All three gunpowder factories closed in 1934. ICI, then the owners, sensed war with Germany, and realised that Faversham would become vulnerable to air attacks or possibly invasion. Work, staff and machinery, were transferred to Scotland. Most of the Marsh Works was later developed for housing and the Oare works is now a nature reserve.

The UK Explosives industry has been regulated under the Explosives Act 1875 and its subsequent revisions until The Manufacture and Storage of Explosives Regulations 2005, which replaced most of the 1875 Act. The most recent legislation is the Explosives Regulations 2014.

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