On Her Majesty's Service WASC 35A

POSTAGE PAID

WASC 35

CRDD. THE CRDD EST. ITS PROGRAMME AND FACILITIES
21.5.1947

WASC 35

/

THE CHEMICAL RESEARCH AND DEVELOPMENT DEPARTMENT,

ITS PROGRAMME AND FACILITIES.

C.R.D.D.,
WALTHAM ABBEY,
ESSEX.

21st MAY, 1947.

THE CHEMICAL RESEARCH AND DEVELOPMENT DEPARTMENT.

ITS PROGRAMME AND FACILITIES.

The Chemical Research and Development Department was officially formed as a separate organisation in October, [illegible]. It was intended that it should eventually be entirely hou[sed at] Waltham Abbey, and that it should take over roughly one-third of the Armament Research Department's staff and programme.

DESCRIPTION OF SITE

The Establishment stands on a site about three miles [long] and about an average of half a mile in depth. It is divided into two main areas by the township of Waltham Holy Cross, the northern half being the old original Royal Gunpowder Factory. It was decided that the southern half should be converted to house the various plant and equipment necessary for propellant and high explosive manufacture, and that the northern site should be devoted in the main to basic laboratory investigations not immediately connected with manufacture.

The buildings on the northern site were found to be convertible with reasonable ease into useful laboratories, and in view of the urgency and importance of work on liquid fuels for rockets and other purposes, the major effort has been expended in erecting and equipping a proof stand, and arranging laboratories to serve it. In addition, plant for the manufacture of plastic propellant on a reasonably large pre-production basis was installed temporarily on the northern site. This will soon be transferred to the southern area.

Other groups of buildings are being steadily converted [into] laboratories: one is already in use for the physical and chemical control of plastic propellant manufacture, another is nearly completed and will be used for researches on the use of hydrogen peroxide as an oxidant. In time the whole of the organic chemical research on explosives will be accommodated in laboratories of this type.

The factory area was originally laid out in relation to the system of water-ways which were used as the main means of transport. We have found it necessary to make provision for roads to give access to our main buildings, nevertheless, it will be very difficult to reach a good many of the buildings by land, and a waterborne service of powered barges is being provided.

GENERAL PROGRAMME OF WORK.

The detailed programme of the establishment has been published already, and is available as an S.A.C. paper (No. A.C.9281/[illegible]). The most urgent items on it are liquid propellants for rockets, plastic and colloidal rocket propellants and cool non-erosive propellants for guns. In addition to this are the chemistry of high explosives and initiators and the development of new or improved processes for their manufacture, the study of the keeping properties of explosives and propellants under tropical storage, the study and development of suitable materials for cartridgeing and packaging of explosives, and determining the compatibility of such materials.

The chemical engineering of explosives manufacturing processes and of appliances to use explosives is being deal[t with] by the formation of a chemical engineering group in the org[anisation]

In addition to the above, the Department also includes a group working for the Home Office on the authorisation of explosives for industrial use and the investigation of accidents arising in industry, and for the study and authorisation of appliances using acetylene under pressure.

The Department has undertaken responsibility for the fundamental physical-chemical work associated with flame warfare, and it will house the Inter-Services Research Group.

STAFF.

The approved complement of staff for this establishment is 173 scientists. At the present time the strength is 119. The organisation is divided into four superintendencies, but at present only two superintendents have been appointed. The Superintendent of Chemical Engineering and a Superintendent for Liquid Fuels Research have still to be found. Attempts are being made to recruit more staff in order to increase the effort that can be applied to liquid and plastic propellants.

The Royal Gunpowder Factory

Waltham Abbey

A brief historical survey

The earliest known record relating to Waltham Abbey Powder-mill bears the date 2nd March 1560-1. On that date, one Marco Antonio Erizzo, an Italian, wrote to John Thomworth (or Tamworth) at Waltham Abbey in reference to a tender he had made to supply the Government with material for making powder. Thomworth was the executor of the widow of Sir Anthony Denny (who died in 1549) and was probably owner or manager of the mill. From 1560, and doubtless even earlier, until quite recently, gunpowder has been made continuously at Waltham Abbey. Accidents appear to have been fairly frequent; five blow-ups in seven years are recorded by Fuller (1648).

Farmer, in his History of Waltham gives a view of the factory as it was in 1735, showing some twenty buildings. The ownership had then passed to Mr. John Walton, "a gentleman of known honour and integrity", and a relative of Izaak Walton, the angler. Power, from about 1739, was supplied by horses, and was used to some extent considerably later than 1770.

In 1770, an Essex historian writes of "curious gunpowder mills worked by water," having an output of 100 one cwt. barrels a week for Government Service.

In 1787 the factory was acquired by the Government from a later John Walton. A pillar sundial bearing his name still stands in front of the old offices in the factory. Surrounding lands were acquired in 1795, by authority of the Board of Ordnance, under whose management the factory then came. In October 1787, forty six hands were employed; in 1791 records speak of double horse mills being in use; in 1795, powder appears to have been sent overland or by barge from Waltham to Purfleet for proof.

Explosions seem to have occurred occasionally at this period, and it is interesting to note that in 1801, after an explosion which killed nine men and four horses, a Committee of the Royal Society visited the works to report on the possibility of danger arising from electrical excitation caused by rolling barrels on the leather covered floors or by the use of silk covered dusting reels. The Committee reported that there could be no danger from such causes.

About 1804 the use of charcoal burnt in retorts or cylinders instead of in pits, was introduced. The annual output of the factory was then about 20,000 barrels.

In 1805 and 1809 water power rights were acquired by purchase of the Cheshunt corn mill and the Waltham Abbey corn mill.

In 1811, a report by General Congreve to the Master General of the Ordnance, dated 20.4.1811, stated that between 1.1.1789 and 31.8.1810, 407,408 barrels of gunpowder, each 100 lbs, made at Waltham and Faversham showed a profit of £288,357-6-0½ and that the profit on "regenerating" 127,419¼ barrels between 1.1.1790 and 31.8.1810, was £53,091-11-3, or a total profit of £341,488-18-3¾. The total amount expended by the Government on original purchase, repairs, erections and improvements between 1787 and December 31st 1799, amounted to £45,683-2-7½.

On 27th November 1811 another serious explosion occurred, killing eight men, and thereafter Bramah hydraulic presses were installed in place of the old screw presses. In 1814 water power was substituted entirely for horse power. At the height of the Peninsular War (1813) there were 24 water mills and 9 horse mills employing about 250 hands. In 1816, the old "corning" frame was replaced by a new granulating machine patented by Congreve, and erected on Lower Island.

From 1832, when the Royal factories at Faversham and Ballincollig, in Ireland, were disposed of, R.G.P.F. Waltham Abbey became the sole Royal Gunpowder Factory, and has remained so to this day.

In 1858 the value of factory holdings was estimated at £230,000.

Col. Askwith was appointed as the first Superintendent on 18th August 1855. In 1858, a system of lightning conductors was installed. In 1870 records speak of 32 pairs of incorporating mills, some driven by water and some by steam. Men employed numbered about 150. Refining of sulphur and saltpetre, and burning of charcoal were carried out entirely in the factory.

Nothing else but black powder was made at R.G.P.F. until 1872, when the manufacture of guncotton was commenced on a large scale. In 1885, one hundred acres of land known as Quinton Hill were acquired, and a new guncotton factory, which started up in 1890, was there erected.

"Brown" powder was introduced from Germany in 1883, and a number of new buildings were put up for its production, which was commenced in 1885.

Smokeless powder (Cordite) manufacture was commenced in 1891. For its production a nitro-glycerine factory was erected on Quinton Hill, together with the necessary cordite process buildings. In 1898 another similar factory was started up in the old part of the factory, necessitating the acquisition of another 94½ acres of land.

In 1909 the factory covered 411½ acres, and produced gunpowder, fine grain powder for fuses and for priming cordite cartridges, picric powder, nitric acid, nitro-glycerine, guncotton, and continued to refine sulphur and saltpetre. Wood for the charcoal was mostly grown on the estate.

/R.G.P.F.

R.G.P.F. during two world wars, has supplied the nucleus of trained staffs for starting up the new ordnance factories, besides producing to its full capacity explosives, propellents and intermediates of very high quality. Experimental pilot plant for the production of R.D.X., was erected here and continued to produce throughout World War II.

In 1945, as part of the general reorganisation of Defence Departments, the R.G.P.F. was relinquished by D.O.F.(X) and taken over by C.S.A.R. with a view to setting up a separate organisation to deal with research on explosives and intermediates from the fundamental stages to plant scale production.

The official inception of the Chemical Research and Development Department took place on October 1st 1945, Dr. H.J. Poole, B.Sc., Ph.D., A.R.I.C., M.R.I., being appointed Chief Superintendent.

PROGRAMME AND ACTIVITIES IN 1947

General Survey of the work of the Liquid Propellants Group.

The primary purpose of the Liquid Propellants Group is to produce propellant combinations which will function correctly and reliably in rocket motors whose dimensions and performance are specified by the various Service Departments. The propellants can be divided broadly into two classes:

(a) Mono-propellants. These are substances or mixtures of substances whose decomposition can be initiated in a rocket motor with the production of hot gaseous products. Examples are Nitro methane, Myrol (mixture of Methyl Nitrate and Methyl Alcohol) etc.

(b) Bi-component systems

(i) Non-self-igniting systems. In these the two components do not spontaneously react when mixed but require an external source of energy (some form of igniter) to initiate the reaction. Examples are Liquid Oxygen and Ethyl Alcohol, Nitric Acid and Paraffin, Hydrogen Peroxide and Paraffin.

(ii) Self Igniting Systems. Reaction commences as soon as the components meet. Examples are Nitric Acid and Furfuryl Alcohol, Hydrogen Peroxide and Hydrazine Hydrate.

To be acceptable for Service use these propellants must be safe to handle, stable in storage and not corrosive of containers. This group must be able to specify physical properties of the components, such as density, viscosity, surface tension so that designers can calculate feed pipe dimensions and injector nozzle dimensions. These properties are measured by standard physical methods and are dealt with as a routine procedure. The job of the group begins with the functioning of the propellant in a rocket motor and can be analysed into five sections.

(1) Injection.
(2) Combustion and Ignition
(3) Expansion of hot gases through nozzle
(4) Cooling of Rocket motor and venturi
(5) Choice of materials.

(1) Injection.

There is a large amount of knowledge on injectors for Diesel motors but in this case the pressure drop across the nozzle is of the order of 1000 lbs/sq.ins. In rocket motors, and also in jet motors, the pressure drop is of the order of 100 lbs/sq.ins. and little information is available in this region. Further the type of injection depends on whether the propellant combination is self-igniting or not. Work in the group consists of (a) collecting the available information (b) deciding what injector characteristics are desirable (c) finding some method of assessing injectors.

(2) Combustion and Ignition

The performance of a rocket motor is measured by the Specific Impulse (S.I.) i.e. the thrust when the rate of propellant feed is 1 lb per sec. The theoretical value is simply, although this

/calculation

calculation is tedious, calculated from the thermodynamic properties of the propellant. The measured value is less than the theoretical value as the result of inefficient injection, heat losses to the motor, incomplete combustion, losses in the jet arising from turbulence at the throat and non-parallel flow. This assessment is carried out in a Proof stand, whose arrangement and function are described in a later section. The object is to produce the smallest motor possible and this requires extensive tests on injectors and addition of catalysts to the propellant. This latter is done partly in the proof stand and also in combustion bombs to measure rates of combustion and to determine the factors influencing this.

So far work on ignition has been concentrated on finding suitable self-igniting fuels for nitric acid. The ignition delay, i.e. delay between mixing and ignition, must be of the order of a few milli seconds. Two methods for measuring this are being developed.

(3) Expansion of Hot Gases through the Nozzle.

The study of the nature of the flow in the jet requires photographic measurements by Schliven and Interferometric methods. Apparatus for this purpose is at present only in process of construction.

(4) Cooling of Rocket Motor and Venturi

This involves laboratory measurment of quantities such as thermal conductivities, critical pressure etc., and proof-stand measurements of heat transfer. This is at the moment, only in the constructional stage and no measurements have so far been carried out.

(5) Choice of Materials

This requires measurement of resistance of material to thermal shock and erosion i.e. loss of material by the flow of hot gases. This is closely connected with questions of heat transfer and detailed design.

In addition to these studies problems have arisen in connection with the attenuation of radar beams by the rocket flame. This is discussed elsewhere but has given rise to detailed spectroscopic and electrical studies of rocket flames.

HYDROGEN PEROXIDE - STABILITY, CORROSION, AND COMPATIBILITY

Hydrogen Peroxide of 80 - 90 per cent. concentration, usually designated H.T.P. (High Test Peroxide), presents a special problem in that, as even under the best storage conditions, a slow decomposition to water and oxygen goes on:

$$2H_2O_2 = 2H_2O + O_2.$$

/Under

Under suitable conditions of bulk storage, using present stabilisers, under British climatic conditions, this decomposition need not exceed one per cent. per year. The mechanism of the decomposition is very complex. Small fractions of a part per million of iron and copper, in solution as ions, have a measurable catalytic effect; studies have been made recently to compare the effects of a number of common ions. It is probable that minute dust particles also influence the reaction; and it is hoped shortly to develop methods of estimating the size and number of dust particles, and of preparing dust-free samples of H.T.P. Much of the decomposition of any sample of H.T.P. probably occurs at the walls of the containing vessel; this necessitates study of the compatibility of H.T.P. with numerous materials to decide whether they are suitable either for long-term storage or for short-term contact.

Materials being tested for compatibility include metals (aluminium and its alloys are the best for storage; austenitic and some non-austenitic steels are also very free from catalytic action); plastics (for storage in the peroxide submarine, and for miscellaneous other uses); textile materials (e.g. for gland-packings and for protective clothing); and lubricants (paraffins and silicones are generally suitable).

The storage of H.T.P. in aluminium does not lead to corrosion if suitable precautions are taken; but under some conditions, especially in the presence of traces of chlorides as impurities, corrosion may occur. Study is being given to various surface treatments to increase resistance to corrosion.

Attempts are also to be made, in collaboration with Messrs. Laporte, Luton, to develop more suitable routine stability tests than that now in use, which was developed by the Germans.

RADIO - ATTENUATION AND ASSOCIATED WORK

The main requirement of this work is to find out what causes the attenuation of radar signals by rocket flames. For this reason the properties of flames are being studied by several means, but owing to difficulties in getting reproducible rocket flames, work so far has been chiefly concerned with laboratory flames, of fairly small dimensions. At Waltham both D.C. and A.C. conductivity measurements have been made, and in general confirmed the view that with pure flames up to about 2000°K, the gases were not appreciably ionized. The addition of salts of easily ionized materials caused a tremendous increase in conductivity, and would be expected to have a serious effect on radar signals. In collaboration with the Admiralty at Witley some measurements on small flames at radar frequency have been made and these experiments are continuing. At Westcott preliminary measurements on rockets on towers (to eliminate ground effects) has now commenced. This Department collaborates closely with both A.S.E. and G.P.D. in the programme of trials, and in provision of suitable fuels.

At the same time, work on the emission spectra of laboratory flames has been started. So far the main effort has been in collecting reference spectra, and adjusting the various instruments. The object of the investigation will be to

/determine

determine from the rocket flames whether combustion in the rocket is satisfactory and complete, and also whether there are present in the flames any unusual radicles or molecules which may be a possible cause of the attenuation. In addition data on flame temperatures (of the order of 3000°K) is required and line reversal methods will be investigated.

At a later stage it is also hoped to utilize some of this information and technique in the development of flame thrower fuels with increased incendiary effect.

NO. 1 PROOF STAND. WALTHAM.

The systematic study of both known and novel rocket propellants involves the study of their ignition and combustion in motors ranging from 100 to 1000 lbs thrust. To enable these motors to be safely observed at close quarters has been the aim of the designers of Waltham Proof Stand No.1.

Two firing pits, two control rooms and one command room common to both pits are the essential feature of the design.

The motors, fired statically, are anchored to a freely suspended cradle. This communicates the thrust of the motor to a diaphragm which converts the force into a hydraulic pressure which can easily be recorded.

The pressure of combustion is recorded during a run by both mechanical and electrical methods, the latter method being chiefly used to elucidate the fine structure of ignition processes.

Other data, such as heat transfer, flame velocity, flame spectra, flame dielectric constant and other important parameters will be measured when the staff position reaches the proper complement for this work.

The first firing pit is devoted to bi-propellant systems, the one at present being used being based on nitric acid with a variety of fuels. In this connection it is interesting to record that the first self-igniting fuel developed at Waltham (W.A.F.I.) has shown its value in giving very sweet ignition and has so far eliminated the troublesome "hard start" associated with some fuels.

The second pit is about to be fitted out, and is for rocket propellants of a more novel type than any hitherto employed. These will be in the first instance mono-propellants in which G.P.E. has some interest.

The first system to be fired in Pit 2. will be Dithekite - a liquid explosive developed by the A.R.D. during the war under the stimulus of Sir Robert Robertson.

Considerable danger attaches to the early work on these mono-propellant systems as an amount of explosive up to 15 lbs weight may be detonated if failures occur. This accounts for the stronger construction of Pit 2.

Two further proof stands for study of liquid oxygen and other systems are being planned.

LABORATORY WORK

The laboratory work associated with ignition problems is covered by the same sub-group (Mr. Warner and Mr. Whitby) and here some 3,600 ignition delays have been measured on the Waltham Abbey ignition test.

It is intended to follow up this test by an impinging jet test, which will help to evaluate the effect of hydrodynamic factors on ignition.

The work has already shown up important phenomena such as the existence of minima in the ignition delays of binary fuel mixtures.

PLASTIC PROPELLANTS FOR ROCKETS

In rocket motors filled with plastic propellant the propellant is pressed directly against the inner wall of the rocket tube so that burning is restricted to a central internal surface. In the early cordite-filled rockets this technique was tried but failed because of the difference in thermal expansion between the propellant and tube which resulted in their separation during temperature fluctuations on storage. With plastic propellant, however, the stresses set up by this differential expansion are relaxed by flow of the propellant itself. The rheological properties of the propellant must be such that the propellant should flow to take up dimensional changes following temperature variations but must not flow under gravitational stresses on storage at high temperatures. The protection of the rocket tube from the hot gases permits the use of thin steel tubes or tubes of light alloy with a resulting saving in weight and increase in the efficiency of the rocket motor.

The initial work on plastic propellant was confined to systems based on ammonium picrate, sodium nitrate and a hydrocarbon type of binder. Recent developments include the replacement of sodium nitrate as oxidant by ammonium perchlorate, giving relatively smokeless propellants having a superior ballistic performance. Compared with the service rocket cordite a twenty per cent in specific impulse and a three-fold increase in burning rate have been achieved with the perchlorate type propellants.

Approx. 100 tons of plastic propellant have been manufactured and subjected to extensive trials in rocket motors chiefly of 5 inch calibre. These trials have been associated with several actual or potential Service requirements, which include the 4-second A.T.O. motor the 5 inch L.A.P./R.P. and the light alloy boost unit for L.O.P./G.A.P.

Fields of current and future research include the development of propellants with a lower temperature coefficient of plasticity, improvement of the adhesion of the propellant to the rocket tube, and the development of methods of testing the adhesion and of inspection of the filled rocket charge.

Examination of alternative highly nitrated binders is also receiving attention.

R.D.X. PLANT

The R.D.X. Plant at Waltham Abbey was the first production unit operated in the R.O. Factories. It came into production in 1939 and comprised two continuous nitration units, identical in design with the original Woolwich plant, and each with a capacity of 75 lbs. of R.D.X. per hour (equal to a total output of about 10 tons per week). The plant was originally installed as a pilot production unit which would provide adequate working experience at every stage in R.D.X. process; complete facilities were provided and are still available for the purification of the R.D.X., its processing into service stores such as RDX/TNT, Plastic Explosive, Oiled R.D.X. etc., and for the recovery and concentration of the considerable quantities of Nitric Acid used in the nitrolysis of the Hexamine.

Under the original operating conditions an Acid/Hexamine ratio of 12½/1 was employed and the nitrolysis was carried out continuously at 25°C. followed by controlled decomposition of unstable by-products in the Diluter. A war-time development introduced on a large scale at Bridgwater consisted of the "duel feed" principle whereby additional Hexamine was fed into the second compartment of the nitrator and the overall Acid/Hexamine ratio was reduced to 10½/1 thus effecting an important saving of acid without seriously affecting the yield. When Acid/Hexamine ratios below about 10/1 are employed there is considerable danger of R.D.X. separating out from the reaction mixture, being deposited on the cooling coils and so preventing control of the reaction. Recent developments have indicated that it is practicable to overcome these difficulties by carrying out the initial nitrolysis at a low temperature (e.g. -20°C), and completing the R.D.X. formation by holding the reaction mixture at 55°C for 10 minutes. Under these conditions the concentration of R.D.X. in the reaction mixture is kept below the saturation limit.

FINE PICRITE PLANT

This plant illustrates the type of semi-scale work that it is intended to carry out in this Establishment. A process for production of picrite (nitroguanidine) in extremely fine crystal size was worked out in the laboratories at Woolwich, and a laboratory size plant was built and operated. From this sufficient data were accumulated to enable the present semi-scale plant to be designed. This plant will enable very fine picrite

/to

to be manufactured in sufficient quantities for extensive ballistic trials in large guns, and for trials as a substitute for carbon black in certain bomb fillings.

The fine picrite has been found to improve the regularity of dimensions and density of gun propellants, and there are strong indications that in certain guns the flashless efficiency is increased.

In its use with high explosives it is found that the picrite prevents segregation of the aluminium in the molten explosive, and since it is itself explosive the mixture is therefore more powerful than when inert carbon black is used for the same purpose.