

THE NITROGEN PROBLEM AND THE WORK OF THE NITROGEN PRODUCTS COMMITTEE.¹

The Nitrogen Problem.

THE war has served to bring into special prominence the fundamental importance of nitrogen compounds, not only for munitions, but also for agriculture.

Nitrogen is an essential constituent of practically all modern explosives, both of the so-called high-explosives and of propellants. The manufacture of the vast quantities that have been called for by the present conditions of warfare has led to an unprecedented demand for various nitrogen compounds.

Nitrogen is also an essential constituent of all vegetation, and the world's production of food is becoming more and more dependent upon the utilisation of nitrogenous fertilisers. The world's consumption of such materials appears practically to double every ten years, and in 1913 had attained the large figure of 2,500,000 tons of Chile nitrate and about 1,400,000 tons of ammonium sulphate.

With the outbreak of war the demand for explosives became of paramount importance, and the requirements of agriculture for the time being took a secondary position. The prospect of a world shortage of food, however, has served to bring the agricultural aspect of the problem again into the forefront. In this connection it is worthy of note that in 1898 Sir William Crookes, in a carefully reasoned statement, directed attention to the possibility of a shortage in the wheat supply of the world and to the vital bearing upon this question of an adequate supply of nitrogenous fertilisers.

The researches of Sir William Crookes and the experimental work of Lord Rayleigh upon the fixation of atmospheric nitrogen by means of the electric arc pointed the way to a method of utilising the unlimited supply of nitrogen in the air, and thus providing against the time when other natural sources of nitrogen compounds should have become exhausted.

The establishment on a very large scale during the past twenty years of processes for nitrogen fixation is one of the most striking electro-chemical developments of modern times. Special reference may be made to the arc process as used in Norway, the Haber or synthetic ammonia process developed in Germany, and to the cyanamide process for the manufacture of nitrolim from calcium carbide as carried on in Norway, Sweden, France, Italy, Germany, and the United States.

In spite of the fact that the incentive to the commercial establishment of nitrogen fixation may be said to have originated in this country, no steps were taken in the United Kingdom to obtain nitrogen compounds other than cyanides synthetically. The ammonia recovered at gasworks and coke-ovens has constituted practically the only form of combined nitrogen produced in this country. During the war the command of the seas has hitherto enabled Great Britain to rely entirely upon importation for the whole of our supplies of nitrate of soda, the most important raw material of our explosives industry. The Central Powers, on the contrary, having been cut off from external supplies, were compelled to fall back upon their internal resources, with the result that nitrogen fixation processes, some of which were established commercially before the war have been developed upon an enormous scale.

Formation of the Nitrogen Products Committee.

Soon after the formation of the Munitions Inventions Department in August, 1915, proposals for the fixation

¹ Abridged from a Report printed for the Munitions Inventions Department by H. M. Stationery Office.

of nitrogen began to be received from inventors. These schemes were referred to the Chemical Inventions Committee of the Advisory Panel, but as they were isolated applications of the general problem and were of limited scope, they did not immediately lead to any definite line of policy being taken upon the question. The importance of the problem was recognised, however, and the attention of the Minister was directed to it from time to time in the monthly departmental reports.

The inauguration of the submarine campaign in February, 1916, and the grave menace to overseas supplies of nitrates emphasised the importance of taking action on the matter. At this opportune moment a memorandum on the nitrogen problem was submitted to the Department by the Faraday Society. Several conferences were held to discuss the steps that should be taken, and as a result the Nitrogen Products Committee was constituted in the following June. Members of the Advisory Panel, representatives of other Departments of the Ministry of Munitions and of the Government, and delegates of the leading scientific societies were invited to serve. The terms of reference to the Committee were as follows:—

(1) To consider the relative advantages for this country and for the Empire of the various methods for the fixation of atmospheric nitrogen from the point of view of both war and peace purposes; to ascertain their relative costs, and to advise on proposals relevant thereto which may be submitted to the department.

(2) To examine into the supply of the raw materials required, e.g. pure nitrogen and hydrogen, and into the utilisation of the by-products obtained.

(3) Since some of the processes employed depend for their success on the provision of large supplies of cheap power, to ascertain where and how this can best be obtained.

(4) To consider what steps can with advantage be taken to conserve and increase the national resources in nitrogen-bearing compounds and to limit their wastage.

(5) To carry out the experimental work necessary to arrive at definite conclusions as to the practicability and efficiency of such processes as may appear to the Committee to be of value.

(6) As a result of the foregoing steps, to advise as to starting operations on an industrial scale.

Nitrogen Fixation Research.

The necessity for research was evident from the outset, and the department at once took steps for the organisation of a suitable research staff and the acquisition of a laboratory. Fortunately, the co-operation of the authorities of University College was secured, and a part of the new Ramsay Laboratory, at that time scarcely completed, was placed at the disposal of the department.

The item placed first on the research programme was a complete investigation into the production of synthetic ammonia by the Haber process. This decision was influenced by the claims made for the process and by the commanding position it occupies in Germany, where the economic conditions as regards coal supplies and the comparative absence of water-power are similar to those in Great Britain. Moreover, the almost complete lack of precise information concerning the commercial details of this process made it apparent that the research would present many unknown factors, and was therefore likely to occupy a considerable time.

Towards the end of the year the Committee came to the conclusion that the ammonia oxidation process was well adapted as an emergency measure for securing quickly a considerable output of nitric acid or nitrates. Although already working with more or less success

upon the Continent, the process had not at that time been operated in this country. A systematic investigation of the most recent developments of the process was therefore undertaken.

Many important problems have arisen in connection with the two main researches indicated above. Reference may be made to such questions as the most efficient and commercially practicable catalysts for the synthesis of ammonia and for ammonia oxidation, and the commercial preparation in bulk and at a sufficiently low cost of hydrogen of the high degree of purity required for the synthesis of ammonia.

Interim Report of the Committee.

In view of the magnitude and complexity of the problem, the Committee was unable immediately to present a complete report. Certain definite conclusions had been arrived at, however, and these, together with recommendations thereon, were embodied in a unanimous interim report, which was submitted to the Minister of Munitions in February, 1917. The substance of the recommendations is given below.

(a) *By-product Ammonia.*—The importance of increasing the output of by-product ammonia for munitions and for agriculture was pointed out. Steps were indicated whereby an increase could be obtained from existing gasworks and coke-oven plants. It was also recommended that action should be taken to avoid the loss of ammonia known to be occurring in certain districts.

(b) *Ammonia Oxidation Process.*—The erection at the earliest possible moment of plant capable of producing in the aggregate at least 10,000 tons of nitric acid per annum from gasworks or coke-oven ammonia was recommended.

(c) *Cyanamide Process.*—The erection of a factory having an annual output of the order of 50,000 tons of cyanamide was recommended, the cyanamide to be utilised as such for agriculture or for the production of ammonia.

(d) *Synthetic Ammonia Process.*—The erection of a full-sized trial unit plant for the synthetic ammonia process was recommended.

The Minister of Munitions invited members of the Committee to meet him, and the recommendations of the interim report were discussed in detail. At the conclusion of this meeting the Minister appointed a small Executive Committee to supervise the action involved in giving effect to his decisions, and to report to him from time to time upon the progress made.

The Minister's Decisions and the Action Taken Thereon.

The Minister's decisions were as follows:—

(a) *By-product Ammonia.*—The Committee was requested to deal with the problem of conserving ammonia and of augmenting the output on the lines of the recommendations.

(b) *Ammonia Oxidation Process.*—The Ministry of Munitions would undertake the installation of one Government plant on the lines suggested, or, if the Committee so advised, the Ministry would agree to the erection of plants by suitable private firms. The information resulting from the research work was to be placed freely at the disposal of *bona-fide* manufacturers, but was not to become the exclusive property of any firm or group of firms.

(c) *Cyanamide Process.* The Committee was requested to investigate the relative merits of a Government scheme and of other schemes that had been put forward involving private enterprise, and to submit a report embodying definite proposals.

(d) *Synthetic Ammonia Process.*—The erection of the full-sized trial unit was authorised.

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In carrying out these decisions the Executive Committee dealt first with the problem of conserving and increasing the output of by-product ammonia. The next step taken was to summon a conference of manufacturers likely to be interested in the ammonia oxidation process, as a good deal of useful information had been collected regarding it and the research work had already reached a semi-commercial stage. Encouraging progress continued to be made with the research, and arrangements and plans were made for the erection in London of a trial plant consisting of a single commercial unit designed to give an output of one ton of strong nitric acid per day. At this stage the work of establishing the process on a commercial scale for the manufacture of nitric acid and ammonium nitrate was handed over to the Explosives Department at its request in August, 1917. The work of investigation however, has been continued at the research laboratory as several important aspects of the process still remain to be explored.

With regard to the manufacture of cyanamide, the Executive Committee came to the conclusion that the schemes involving private enterprise did not adequately fulfil the ends in view, and recommended the erection of a factory by the Government. The committee proceeded to collect further information on cyanamide processes in actual operation, and representatives proceeded overseas for this purpose. Complete details of a scheme involving a large-scale factory with electric power station are now in course of preparation for submission to the Minister of Munitions.

Meanwhile a considerable amount of work had been carried out in connection with the synthesis of ammonia, including a detailed investigation of the whole of the conditions governing the process, and of the efficiency and life of numerous catalysts. These studies led to the devising of a method of working whereby the output of ammonia per unit of catalyst space has been increased to a figure which, so far as is known, exceeds anything hitherto attained. The design and erection of a semi-technical unit apparatus embodying a number of novel features, with the necessary pumps, circulators, gas-holders, etc., were then undertaken. It is expected that the operation of this unit, which is now at work, will enable the remaining problems as to the chemical engineering details involved in the design of the full-sized trial unit authorised by the Minister to be definitely settled.

Research upon the preparation of pure hydrogen in bulk has been carried on conjointly with the above investigations, and arrangements have already been made for the trial on a semi-commercial scale of a process that has given very promising results in the laboratory.

Nitrogen in Sulphuric Acid Manufacture.

An important practical outcome of the conferences with manufacturers has been the introduction of ammonia oxidation plant to take the place of the nitropots used in the manufacture of sulphuric acid by the leaden chamber process. In pre-war times the annual consumption of Chile nitrate for this purpose amounted to 18,000 tons. With the present increased output of sulphuric acid the consumption is greater, so that the possible saving of overseas freight is appreciable.

One of the small converters designed in, and made for, the Departmental Research Laboratory has been installed at the sulphuric acid works of Messrs. Brunner, Mond, and Co., and has been working satisfactorily for some months. The firm is now arranging to adapt similar converters to the whole of their leaden chambers. The United Alkali Co., the South Metropolitan Gas Co., and others are making arrangements to adopt the process, and are utilising two types of converter to the laboratory designs. Drawings have

also been placed at the disposal of the Explosives Department for the benefit of other controlled establishments.

The apparatus is compact; the expense involved in its installation, apart from ammonia purification plant, is comparatively small, and its operation is simple. Arrangements have therefore been made for the rapid manufacture of the converters likely to be required, since it is believed that these designs may become standard types for the purpose in question. An explanatory pamphlet, compiled by the research staff and embodying detailed information concerning the construction and operation of the converters, will be available shortly for the use of firms which have already taken up the process or are desirous of doing so.

Further Research.

Up to the present date the research has practically been confined to the two processes mentioned above and to problems arising therefrom. The investigations of the Committee have shown, however, that many important and promising fields still remain to be explored.

In present circumstances all activities have been concentrated upon processes which have a possible value as war measures, and no attempt has been made to extend the programme of research beyond such limits. In view, however, of the national importance of the nitrogen problem, both now and in the future, it is hoped that definite arrangements will be made to preserve the continuity of the research after the war.

The Importance of Cheap Electric Power.

It was realised from the outset that the generation of electric power at a cost decidedly lower than has hitherto been attained in this country was a vital factor if an attempt was to be made to establish certain of the nitrogen fixation industries in Great Britain on a sound economic basis from the point of view of post-war competition. A thorough inquiry has therefore been made as to the possibility of cheapening the production of electric power from coal, not only by its generation in bulk with the most modern plant, but also by the use of methods involving carbonisation and gasification, with recovery of the ammonia, fuel oils, and other by-products hitherto wasted when raw coal has been directly used. The sub-committees concerned have had the advantage of obtaining the personal views of a number of experts who attended to give evidence on different aspects of the problem. This inquiry has been distinctly fruitful, and much detailed information has been collected.

Schemes for the utilisation of various undeveloped water-powers in the British Isles for nitrogen fixation have also been submitted and carefully examined. At least one of these schemes for hydro-electric development on a considerable scale presents *prima facie* prospects of becoming a valuable national asset. The Power Sub-Committee recommended that a survey should be made of the drainage area in question with the view of confirming the details of the scheme as submitted. The survey has recently been completed and is expected to result in the formulation of a definite development scheme for the utilisation of this water-power. It is estimated that the engineering work involved will take about two years to complete, and the scheme is therefore to be regarded as a post-war measure.

Costs of Operating Nitrogen Fixation Processes.

Since many of the nitrogen fixation processes have not only a value for munitions, but also a post-war importance, endeavours have been made to investigate the probable requirements of this country for nitrogen products. A detailed examination has been made of

the production, consumption, imports, and exports of such products, and special consideration has been given to the question as to the relative order of the costs involved in operating the synthetic and non-synthetic processes.

Most of the information relating to synthetic processes has had to be obtained from foreign sources, and the Committee has been able to secure many figures of an authoritative character. The information thus collected has been subjected to critical examination in the light of manufacturing experience in allied industries, and conclusions have been arrived at as to the costs likely to be incurred under British conditions.

The magnitude of this part of the inquiry may be measured when it is stated that the Committee is in possession of comprehensive data concerning the cost of manufacture of:—

- (a) Nitric acid and nitrates by the older methods, and by the arc and ammonia oxidation processes;
- (b) Calcium carbide and cyanamide;
- (c) Ammonia and ammonium sulphate by the Haber and cyanamide processes;
- (d) Hydrogen and nitrogen;

as well as concerning the costs involved in operating the Chile nitrate and the by-product ammonia industries.

Nitrogen Fixation in the United States.

The action taken by the United States Government on the nitrogen question is worthy of notice. Under the National Defence Act of 1916 a sum of 4,000,000l. was set aside for the establishment in the United States of nitrogen fixation on a large scale. Committees of the National Academy of Sciences, and afterwards of the Ordnance Department, were set up. Their advisers visited England and the more important nitrogen fixation installations on the Continent outside Germany. Upon the recommendation of their experts, the U.S.A. War Department has decided to erect forthwith works for the manufacture of synthetic ammonia by a modified Haber process.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

LEEDS.—At the meeting of the council of the University, held on November 21, the following extract from Prof. Cobb's annual report as Livesey professor and head of the Department of Coal-gas and Fuel Industries was read:—"A valuable donation of carbonising, washing, and purifying plant has been promised, which, in the near future, should prove of very great service to the department and the gas industry; but the erection of the plant must await the conclusion of the war. When installed, this plant is intended to serve as a connecting link between the apparatus of the laboratory and plant on the full working scale. It should allow of the production of any quality of coal-gas and water-gas required for experimental purposes, and will, moreover, from the possibility of exact control and ready modification of its parts, allow studies to be made on the influence of varying conditions of operation which it is hoped will be of a high order of usefulness, both for training and research. For this gift the University is indebted to the generosity of Mr. Henry Woodall, jun., who expresses himself in a letter of June 8, 1917, as happy to provide and erect the plant, 'free of cost, to the University in memory of my late father and partner, whose interest in the University was very deep and sincere.'" The council accepted the offer with great pleasure, and expressed its most sincere thanks to Mr. Woodall for his generous gift.

THE annual meetings of the Geographical Association are to be held on January 5 and 7 next at the