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# THE NITROGEN PROBLEM OF THE UNITED STATES.

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I. General Statement.

The nitrogen problem is somewhat different from the problems we face with reference to other raw materials with which this country is not amply supplied, as for instance tin, for there is an unlimited supply of nitrogen as such always and everywhere available. When we remember that four-fifths of the air we breathe is nitrogen, and that all nitrogen consumed returns to the air, we realize that we have an inexhaustible supply constantly at hand.

The problem, therefore, is to make this supply available in the form and quantity desired. Nitrogen by itself does not fulfill our wants. It is necessary first, that the air nitrogen be fixed to some other element and then, that this combination be converted into the particular substance desired. Until recent years, however, human efforts were not able to fix nitrogen to some other element. And they were only able to change the form of nitrogen compounds to a very small extent. But within the last few years scientific knowledge has so advanced that we are now able to accomplish both these objectives.

Nature is constantly at work fixing air nitrogen and it is the deposits resulting from such work of nature thru the ages that have been and still are our main source of supply. The present day solution to the nitrogen problem from the standpoint of supply is therefore dependent upon nature's present and past activities as well as upon the works of man.

While fixed nitrogen is essential to present day warfare for strictly military purposes, it is equally necessary to the present day peace time life of the nation. In time of war requirements for this latter purpose must still be met. It follows that a military discussion of the nitrogen

problem requires a round-up from both the military and the commercial standpoints.

II. Early History.

The nitrogen problem in national preparedness is not a new one. It is probably the oldest problem in munitions supply with which armies of civilized nations have had to struggle. It is, in fact, the mother.

Nitrogen does not readily combine with other elements. And after it is combined it is extremely prone to decomposition with the almost instantaneous development of heat and gas - which mean explosive force. It is this quality which has made nitrogen so important in the explosives field for many centuries, and it is still vital to their production.

History tells us that the alchemists of the 8th century knew of mixtures of substances which would burn so quickly as to develop explosive force. The essential substance in such mixtures was a nitrogen compound known in the earlier days as salt petre, but known today as potassium nitrate.

The people of that day worked under the same incentives as the people of today. They were always in danger of war and consequently were always endeavoring to find means by which they could defeat the enemy. They realized that the force contained in this new substance would be very helpful if it could be applied against the enemy and they set about developing methods of harnessing it. We do not hear of its use in battle until about 1250, when one of the European armies burned powder in a gun for the purpose of hurling a projectile against the enemy.

This started a new era in warfare. It was the first major application to warfare of the combination of chemistry, mechanics, and engineering. Since that day armies have realized the tremendous power stored in chemicals and have constantly endeavored to utilize more and more of this force thru the medium of mechanical, electrical and other scientific developments.

The use of powder immediately produced serious problems for the armies of the middle ages, especially in the matter of nitrogen. The powder consisted of a mixture of potassium nitrate, charcoal and sulphur. The two latter substances could be generally obtained. But potassium nitrate was not so readily available. The only important deposits are located in India, and their usefulness depended upon a nation's ability to keep open the trade routes.

The armies of this period were therefore constantly faced with the problem of providing a supply of this essential raw material. And they apparently endeavored to solve this raw material problem in about the same way that we are trying to solve it to-day; first, by maintaining the availability of the foreign source; second, by developing a domestic source; third, by developing substitutes; and fourth, by maintaining reserves.

It so happens that animal liquids contain considerable nitrogen in the form of ammonia. Wood ashes contain potassium. In the presence of limestone these two materials gradually combine and form potassium nitrate. In application of this principle "nitrate farms" have for several hundred years been relied upon especially in time of war to convert animal liquids into potassium nitrate. This was their domestic source.

History states that in France, during the wars of the Revolution, when nitrate from India was not obtainable, the process of running nitrate farms was made compulsory by a decree of the convention and that some 2,000 tons of potassium nitrate per year were obtained.

At an earlier date, every land owner in Sweden was obliged to furnish the government each year a certain quántity of home made salt petre, and we are told that all sorts of animal refuse were used up in special "salt petre plantations" and that about 100 tons were obtained per year. This was a combination solution of war reserves and home industry.

In our own country during the Civil War, the south had to rely in great measure upon similar farms for the production of nitrates for powder.

During the Crimean War when Russia was prohibited from obtaining nitrate from India due to Great Britain's participation therein, a process was developed for making potassium nitrate from sodium nitrate. This was a major operation in substitution.

For 600 years, or from 1250 to 1875, black powder continued as practically the sole explosive used in warfare and all efforts were towards increased and more efficient use of it. But from 1875 to the present date the development of powder and explosives has been very rapid. Knowledge for some time had beem growing and by this time was quite well advanced, which allowed of the manufacture of other explosive compounds of nitrogen such as nitroglycerine powder, nitrocelluose powder, T.N.T., dynamite, explosive "D" and all the rest. It is interesting to note that we were still using black powder as our principal propellant in the Spanish War. Smokeless powder was only invented about

1886, and did not come into general use until the beginning of the present century.

III. Requirements of Nitrogen.

1. For strictly military purposes.

With the development of the nitrification of cotton. toluol, glycerine, etc., and their tremendous consumption in shell, mines, bombs, etc., the demand for suitable fixed nitrogen compounds for war purposes has very materially increased.

We have already seen how Sweden by its farms was able to produce only some 100 tons of nitrate per year, which would equal about 14 tons of nitrogen.

In the Napoleonic wars, France produced 2,000 tons of nitrate per year, equal to 280 tons of nitrogen or over 20 times Sweden's consumption.

With the man-power, armament and rate of fire in effect at the time of the World War armistice, one division required for its powder and explosives approximately 2500 tons of fixed nitrogen per year or nearly ten times the amount used by the entire French Army per year during the French Revolutionary period.

A study of Mr. Crowell's "America's Munitions" shows quite conclusively how extremely large has been the increase in the rate of fire of ammunition and in the total consumption thereof. It shows that during one month of 1918 (which was the average of the year 1918) the French and British consumed over two and one-half times the number of rounds of artillery ammunition that were consumed by the Union Forces during the entire Civil War. This would in general correspond to a ratio of 120 to 1. But due to the increased use of

explosives, the proportionate consumption of nitrogen is still greater.

During the year 1918 we were consuming inorganic nitrogen in the United States at the rate of some 420,000 tons and of this over 60% was for strictly military purposes. This consumption for military purposes alone was nearly 1,000 times the French consumption during the Napoleonic wars.

It is difficult to forecast what our requirements for nitrogen for strictly military purposes will be in a future war as they will in great measure depend upon the enemy or combination of enemies that we are called upon to fight. But based upon the experiences of the past there is every reason to believe that future requirements in a major war effort will be materially greater than the already gigantic demand.

2. For industrial purposes.

The demand for fixed nitrogen for peace pursuits can be divided into two main classes:

(a) fertilizers
(b) the chemical industry.

(a) Nitrogen for fertilizers-

The three essential elements of a complete plant food are fixed nitrogen, phosphoric acid and potassium. And of these three, nitrogen is claimed to be the most important and it is the most expensive.

Fertilizer has, since the earliest days of human history, been used in the growing of plants. In the first instances it consisted in placing back on the farm the droppings of animals as well as the remains of crops. As chemical development has progressed, however, study

has been made of just what elements are needed and in what form they should be used to properly sustain and develop plant life. As a result of this, knowledge has been gained as to the inorganic or mineral materials that can be used to augment as fertilizers the organic substances previously used. One such substance is fixed nitrogen in one form or another.

Food must be raised in war as well as in peace. But due to the decrease in farm hands through their enrollment in the army and through their employment in munitions and war plants of various kinds, it may be difficult to work as many acres. In time of war it may therefore be necessary to raise more crops per acre, per man. And the only way this can be accomplished is through the more abundant use of fertilizer.

It must also be remembered that the present civilization is demanding more from the farms. A constantly increasing percentage of our population is living in cities and purchasing their food stuffs rather than raising them. In addition the natural deposits of plant food in our used soils are constantly decreasing. The result is that more and more fertilizer must be used in the form of inorganic materials and especially fixed nitrogen.

The first use of inorganic manures occured about 1850 as a result of German research development and it was some 25 or 30 years later that the use was taken up extensively in the United States. It has expanded very rapidly until today the normal consumption amounts to some 8,000,000 tons per year. The corresponding normal nitrogen content is about 200,000 tons, although due to the farm depression, in

the last few years, actual consumption has been less.

(b) Nitrogen for the chemical industry-

Nitrogen is vital to that part of chemical industry consisting essentially of domestic explosives, refrigeration, the manufacture of dyes, artificial leather, photographic films, celluloid, and other products of nitrated cotton.

We all know of the field of domestic explosives - how they are being used in constantly increasing amounts to mine metal ores, coal, rock, etc., to displace human labor in the excavation of ditches and foundations, the planting and cutting of trees, etc., - and we know how important it is that this use be provided for in time of war.

The principal material used in refrigeration is ammonia, which is about 80% nitrogen. Refrigeration is constantly increasing during peace and in time of war it jumps very rapidly.

The manufacture of dyes, artificial leather, photographic films, celluloid and other products of nitrated cotton is very much an infant industry in the United States. It is, however, rapidly growing. Some parts of it could be dispensed with in time of war, but many could not.

This entire field is a product of the development of knowledge which allows us to nitrate certain bases by the use of nitric acid, and was only started some 40 years ago. Its growth was at first slow, but in later years, the progress has been more rapid until today over 100,000 tons of fixed nitrogen are consumed per annum.

As a general statement of the rate of growth of the use of inorganic nitrogen it seems to be the experience of the world that it doubles every ten years.

IV. Sources of Nitrogen.

Excluding organic nitrogen, the great part of which is used as food and nearly all the balance as home farm fertilizer, we are dependent for our supply of nitrogen on -

(1) By-product coke ovens and gas works
(2) Chilean nitrate
(3) Nitrogen fixation.

1. Nitrogen from By-product coke ovens and gas works:

At present this is the main source of inorganic nitrogen in the United States. By-product coke ovens are most important to the future of America.

Coke is produced from bituminous or soft coal by driving off from the latter all of the volatiles and retaining only the carbon and ash. The coking of coal was developed with the iron industry, coke being necessarily in the blast furnace to form pig iron. In the early days coal was coked in bee-hive ovens in which the coal was heated sufficiently by the burning of a portion of it to drive off the volatiles. These volatiles amounting to approximately 28% of the weight of the coal are, however, extremely valuable and in recent years steps have been taken to capture them through the use of by-product coke ovens. As compared with the production of approximately .65 ton of coke from a ton of coal by the bee-hive process - a by-product oven will produce approximately .72 tons of coke (or 10 per cent more) and in addition some 4 pounds of fix-

ed nitrogen in the form of ammonia, 10 gallons of tar, 5000 cubic feet of gas and 2¾ gallons of light oil or motor spirit. All of these are valuable and in general terms the value of the products from this oven is about 50% greater than from the bee-hive oven. The light oils can be used as motor spirit in time of peace and furnish toluol and benzol for the manufacture of explosives in time of war.

By-product ovens were developed by the Germans and were first introduced into America in 1893. From this time until 1914 when the World War started, development was such that only approximately 25% of the total coke used in the United States was coked therein. Since then the increase has been rapid. Growth was developed during 1915 and 1916 by the purchase by the Allies of the by-products at excessive prices. In 1917 and 1918 the Ordnance Department, in order to obtain increased supplies of toluol and ammonia, further spurred on the construction of by-product ovens. As a result of these efforts and commerical growth, the country is at present coking in by-product ovens some 75% of all of its coke.

The construction of ovens in excess of demands for their main product - coke, and simply to obtain such valuable military by-products as nitrogen, and toluol, could only be justified as an extreme war measure as the initial cost is very high, the time of construction long - and the salvage value for other purposes negligible.

Today the United States is getting about half of its peace-time inorganic nitrogen requirements from coke ovens.

Nitrogen is produced in gas works from coal in a manner similar to the by-product oven. The quantity is relatively small.

2. Nitrate of Soda from Chile.

The rainless deserts of Northern Chile contain a vast supply of raw material called "caliche" from which the commercial salt known as nitrate of soda or Chile Saltpetre is refined. It is estimated that there are some 200,000,000 tons of nitrate available from known supplies of caliche. Production averages about 2,000,000 tons annually. At this rate the known supply will be sufficient for one hundred years. However, the explorations upon which these figures are based have not been thorough and it is possible that the existing reserves are considerably greater. It is constantly becoming more and more difficult, however, to obtain the material. In 1901 the average nitrate content of the caliche refined amounted to 28%, 1909 it amounted to only 19%. In 1881 the quantity of ~~refined~~ nitrate produced by an individual laborer was 73 tons per year while in 1911, it has fallen to 56 tons.

This supply of material has been of tremendous importance in the development of the chemical, as well as of the fertilizer industry. The present era of explosives, dyes, artificial leather, etc., is dependent upon the reaction between some base and nitric acid. And practically all of the nitric acid manufactured up to the World War - and all of it used in that war, except by Germany, was made from Chilean Sodium Nitrate. And even today practically entire dependence except by Germany is had on this material for the manufacture of nitric acid. We are at present able, however, to manufacture nitric acid from ammonia, although at increased cost, and our absolute dependence upon sodium nitrate is thus stopped.

Again - sodium nitrate was practically the first inorganic nitrogen compound used in fertilizer, and today is very largely used for this purpose.

During the World War the United States was dependent upon imported Chilean nitrate to supply over 75% of its inorganic nitrogen demand, and imported during 1918 some 2,000,000 tons of nitrates. Today the country obtains about half of its peace time requirements of nitrogen from Chile.

(3) Fixation of Atmospheric Nitrogen.

Scientists have long recognized that the nitrogen supply of the future will depend upon the fixation of atmospheric nitrogen. They have been diligently working upon the solution of this problem and have made such progress that several methods are now in operation in various parts of the world. The three principal processes are:

a - The Arc process.
b - The Cyanamid process.
c - The Synthetic Ammonia process.

a - The Arc process.

The Arc process is the most direct of all processes and consists of burning air in the intense heat of an electric arc. The nitrogen of the air and the oxygen of the air are thus combined with the formation of an oxide of nitrogen. This latter can then be converted into nitric acid and in turn into powder and explosives or can be converted into sodium nitrate and other salts.

This process is well known throughout the world, but is not in common use because of the tremendous amount of power required. To fix one ton of nitrogen by this process requires some 67,000 k.w. hours

of electricity, which are the equivalent of approximately 10 horse power at work constantly throughout the year. There is one small arc plant in the U.S., located in the State of Washington. The real home of the process is in Scandinavia where cheap water power exists.

b - Cyanamid process.

In the Cyanamid process it is first necessary to manufacture calcium carbide or the material in common use for the production of acetylene gas. The nitrogen of the air is separated from the oxygen of the air by the liquid air process and the nitrogen so obtained is then combined with the calcium carbide. The resultant product is cyanamid. The cyanamid nitrogen can then be converted into ammonia nitrogen, then into nitric acid, and then into nitrate nitrogen. It can also be converted into various other forms of nitrogen useful in fertilizers and other products. This process is also well known throughout the world. Among others there are plants in Germany, Scandanavia, Japan and Canada.

This is the process installed in the government's nitrate plant No. 2 located at Muscle Shoals, Ala., which was constructed during the war at a cost of some $66,000,000. This plant can fix yearly about 40,000 tons of nitrogen in the form of cyanamid, can convert all of this into ammonia, can convert about half of the ammonia into nitric acid and then can combine the ammonia and nitric acid into the military high explosive ammonium nitrate.

In this process also the power consumption is high. To fix one ton of nitrogen requires about 15,000 K.W. hours, or about 2-1/3 horsepower years. To operate the No. 2 plant requires a continuous

supply of approximately 100,000 horsepower. It is interesting to note that the chemical part of this plant was ready to operate several months before its main steam power plant was available. In other words, power was the weak link.

c - Synthetic Ammonia process.

In the synthetic ammonia process the nitrogen of the air is welded to hydrogen with the formation of ammonia. It is also known as the Haber process.

There are two principal methods of obtaining the hydrogen which is the expensive element in this process - one by the electrolysis of water and the other by breaking up water through the use of coke, called the water gas process.

If the former method is used the process requires about as much power as the cyanamid process. If the latter method is used, the power requirements are reduced to approximately one quarter.

The synthetic process is looked upon at the present time with the most favor by scientific men. It involves complicated chemical and engineering problems which are only partially solved from the standpoint of efficiency, but are sufficiently solved to make the process work.

The synthetic process is in use in Germany, France and Italy. Since the Armistice three small plants have been started in the U. S. It is the process installed in U.S. Nitrate Plant No. 1 at Sheffield, Ala., which was the pilot plant in this country. While it did not work satisfactorily, it showed the way for the construction of the first commercial plant located at Syracuse, N.Y. The No. 1 plant

also contains sub-plants for converting ammonia into nitric acid, for concentrating nitric acid, and for manufacturing ammonium nitrate. These sub-plants were successful.

V. Present Status of the Business of Nitrogen Fixation & Conversion.

The development of nitrogen fixation and conversion is a result in great measure of the World War. It required this war to bring home to the various nations the importance of nitrogen and their dependence upon foreign sources. It is interesting to note that Germany did not enter the war until she had developed two methods of fixing nitrogen, namely, the cyanamid and the Haber. Today she leads the world in nitrogen fixation and is entirely self-sustaining.

In this country we know how to fix nitrogen by several processes and we know how to convert the nitrogen into the various desired forms. However, the business of nitrogen fixation in America is only in its infancy. The nitrogen production from America's four operating plants is almost negligible. Nitrogen fixation must fight the battle of economics with the natural sources, or by-products coke ovens and Chilean nitrates. It has scientific developments, an increasing market and decreasing supplies of the natural deposits in its favor and it seems sure, therefore, in the long run to prosper. The sooner this result is brought about, the surer will be our solution to the nitrogen problem.

VI. The Military Solution of the Nitrogen Problem.

The same basic principle applies to the solution of the nitrogen problem as applies to all the important items of supply of a country at war, namely, there must always be available sufficient stocks to supply the country until such stocks can be replenished.

In the nitrogen problem we have nothing to fear unless we are cut off from importations from Chile. But inasmuch as this is possible the solution assumes that we will be deprived of Chilean nitrate.

Our main reliance in time of war for increased nitrogen production would be in nitrogen fixation plants. Experience indicates that with proper plans it would require some 17 months to construct new plants, deliver the products thereof to powder and explosive plants, manufacture the powder and explosives, assemble them into ammunition and finally deliver the latter to the firing line. Such plants could be constructed with sufficient capacity to meet any reasonable requirements.

Our problem, therefore, is to have always available the necessary plans for such expansions and at the same time have available the most economical combination of stocks plus production facilities which will supply the country until the expansions are available.

It is obvious that many assumptions must be made in order to reach a solution. Any change in these assumptions gives a different answer.

Let us assume that domestic commercial production of nitrogen plus commercial stocks of nitrogen materials would take care of

commercial demands in time of war. The Army would then have the problem of taking care of its own needs. On this basis we must have under Army control sufficient stocks of nitrogen plus production facilities to supply our Army until we can erect new plants and deliver their products to the firing line.

Our requirements are dependent upon mobilization, armament and rate of fire. With these data we can develop our cumulative requirements.

The government has retained as a reserve to be available for war time production nitrate Plant No. 2. We know with reasonable accuracy the production by time we can expect from this plant. Under the assumption made, this would be our only producing plant until the new plant's ~~production~~ were available. The products from this plant therefore give our cumulative production.

Our stocks of nitrogen must be equal to the maximum difference between cumulative requirements and cumulative production. And these stocks must be in a balanced condition, or, in other words, some must be as nitrate of soda, some as powder and explosives and some as assembled ammunition.

Just such a solution has been worked out by the Ordnance Department and the Army is now reasonably prepared in nitrogen.

In the days to come new solutions must be worked out, and if, as seems probable, nitrogen fixation develops on a large commercial basis, it will not be necessary to retain Nitrate Plant No. 2.

The great requisite to the maintenance of a nitrogen solution however is the development of knowledge in responsible officials of the Army to the end that they understand the problem and have always available a well

planned out and up-to-date solution. They must also be able to modify the solution to meet the changed condition that a major war will almost surely develop.