THE NITROGEN INDUSTRY

G. D. HONTI

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MACHINERY

From its very beginning the history of the nitrogen industry has perhaps been more closely related to that of the equipment and machines used in the processes than anywhere else. It has been seen in Chapter 1 that the ammonia synthesis and high-pressure techniques were born at the same time; and every step forward marked by some new, often revolutionary, process feature was always interconnected to one or more similarly new or revolutionary achievements in the mechanics employed. This very close relationship between process, constructional materials and equipment in the past (Chapter 1), the present (Chapter 2) and the future (Chapter 9) makes it compulsory for a monograph on the nitrogen industry to include chapters on machinery and equipment. The modern nitrogen industry deals with very large volumes of gases (hundreds of thousands of Nm^3 hourly) and liquids (several thousand m^3 hourly), at medium and high pressures at very high or very low temperatures, and often under severe, corrosive conditions. Solid material is also handled in large volumes (several hundred tons per hour) in the processes. Thus, the requirements imposed upon machinery and equipment are unusually high. Machines of specific construction are used for generating process conditions and forwarding materials, while vessels of equally special type serve to carry out process operations, and piping and fittings connect all the parts in process units. In accordance with the general purposes and aims of this book, Chapters 4 and 5 will rely on the general knowledge of the relevant principles and basic facts already acquired, and will mainly be confined to the description of the special features.

The subject of the machines used in the nitrogen industry embraces practically everything. To cover the whole would require a Machinery Handbook the scope of which would be beyond this work. Nevertheless the machines specific to this industry can be restricted to a few main groups. Solid-material handling equipment and blowers, for example, are quite identical to those used in any other branch of industry. After careful selection, the compressors and pumps form separate groups, while all other specific machinery has been collected in the third group.

Compressors

Compressors are the most important machinery used in the nitrogen industry. Air separation units, synthesis gas production and purification, and ammonia synthesis handle large volumes of different gases under various pressures up to 1000 atm, and all rely on compressors as basic machinery. Nitric acid, urea, and even ammonium nitrate processes nowadays depend increasingly on compressors. Of the very large family of compressors we shall restrict ourselves to the reciprocating compressors from among the positive displacement types, and to the centrifugals from among the rotary machines. These two types have developed special constructions for the nitrogen industry and constitute the basic machinery of every nitrogen works; they therefore deserve a detailed description whereas the other types, if used, are neither specific, nor vital. Nevertheless, a short mention of rotary type displacement machines will be found in Chapter 4.1.2.

Reciprocating or centrifugal? It would seem at first as though this question were pointless. It is well known that for syngas compression in a 1000 MT/day ammonia plant a centrifugal machine is the only answer, while a 300 MT/day plant has to stick to the reciprocating machine. If the historical evolution, the future trends and the transitory cases are considered, the question becomes better founded. Let us briefly recall the main advantages and disadvantages of each, therefore, and define their respective fields of use.

Reciprocating machines can be built from the smallest to the very big units (nowadays up to ~ 10,000 HP and end-pressures of 7000 atm and more) with good efficiency and easy delivery and pressure control. Their main disadvantage is relatively low speed which is worse than all other drawbacks: expensive drive, large space requirement, high maintenance work (need of a building with a crane), large and strong foundation and stand-by units for safe continuous operation. All this makes the use of reciprocating machines expensive. Nevertheless, in the first 50 years of the nitrogen industry they dominated the entire field of ammonia synthesis. The main syngas compressors (the very symbol and representative machinery of every nitrogen works) were always and everywhere of the reciprocating type. A steady progress led first to the large, slow (125 r.p.m.) six-stage horizontal machines with saddle-motor drive up to 16,000 Nm^3/h capacity (late thirties), and after the Second World War to the big (8000 HP) medium-speed (300-500 r.p.m.) boxer machines adapted to the pressure gasification processes and uniting the syngas compressor cylinders with the oxygen or air compressors, recirculating compressor and others in one unit. The centrifugals appeared first in air compression for the oxygen plants, then gained place in the other low pressure difference fields, such as refrigerating machines, ammonia synthesis loop recirculator (glandless Maulwurf pumps with built-in electric drive), and finally began their conquest of the syngas field. Initially a combination of centrifugals (for the first part of the compression) and reciprocating machines (for the end-compression) was introduced. Soon, however, the big units requiring large quantities of gas, together with the new process which was highly suitable for the single-line concept and which produced enough high-pressure steam by waste-heat recovery to drive the compressors, led to the necessity and possibility of the all-centrifugal plant.

Let us consider the advantages of the centrifugals, and the reasons why their use was delayed for so long. The capacity-dependence of the efficiency of a reciprocating machine is not very significant. The capacity of one unit is unlimited at the lower end, but strongly limited by construction and workshop considerations at the higher end. With a centrifugal machine, the capacity is limited at the lower end for two reasons. First, the minimum possible delivery volume is fixed by the necessary end-pressure. In the last stage there must be a minimum effective gas volume, since the impeller channels cannot be made under certain dimensions. Second, the efficiency, which is usually somewhat lower than for reciprocating machines, drops severely towards the lower capacities until it becomes unbearably low. This is connected with the fact that the clearances between the impeller and case cannot be decreased below a certain limit, and the relative importance of the resulting fixed gas losses increases with the reduction of the delivered quantity. The primary condition for the centrifugals in the nitrogen industry therefore was big quantity. When this arrived, the advantages appeared immediately. Centrifugals with their very high speed (3000-16,000 r.p.m.) need considerably less space, and are very suitable for direct drive by steam turbine. The well-balanced, vibration-free machine requires a much simpler foundation. Wearing of the different parts is minimal; continuous running for 8000 hours is usual, and therefore less maintenance and supervision work is needed; installation outside and without stand-by is possible; the savings in investment and running costs are the higher the bigger the plant.

One disadvantage must also be mentioned. The centrifugals can be regulated without by-pass only down to 70-75% of the rated capacity, whereas the value for reciprocatings is much lower. Nevertheless, in modern ammonia plants a lower utilization of the plant (apart from short emergency periods) is out of the question anyway. Figure 4.1.1-1 gives the fields of utilization of the different machines as a function of volume and pressure It is a useful guide for selection, but only a guide.

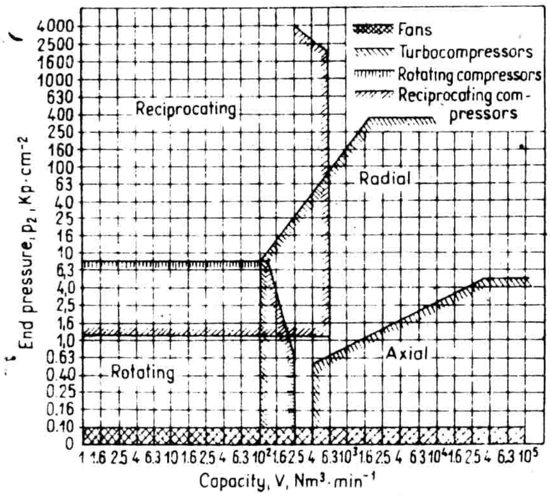

Fig. 4.1.1-1 Field of utilization of the various types of compressors

4.1.1 Reciprocating compressors

4.1.1.1 Theory [1-9]

<u>Single-stage compressor.</u> The theoretical p-V diagram of the compressor is shown in Fig. 4.1.1-2. Straight line 1-2 represents the suction of the gas, curve 2-3 the compression, and straight line 3-4 the discharge of the gas into the high-pressure space. Beginning with point 1, the process repeats itself. The area 1-2-3-4 on the diagram is proportional to the work of the compressor. The diagram of an actual machine, however, differs considerably. It was assumed in the theoretical diagram that the volume is proportional to the stroke,

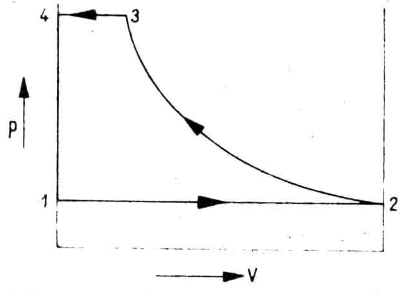

Fig. 4.1.1-2 Theoretical p-V diagram of the compressor

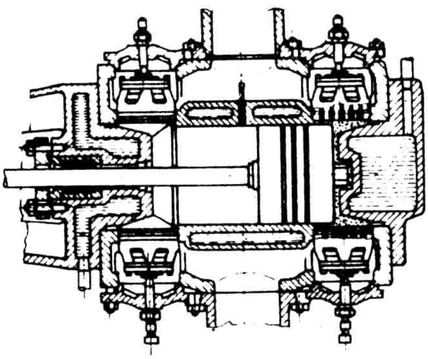

Fig. 4. 1. 1-3 Clearance of a reciprocating compressor

i. e. that the piston touches the cylinder cover at the end of the stroke. This is impossible because of constructional and workshop limitations and therefore a small gap must be left between the piston and the cylinder head. moreover. the valves cannot be connected directly to the theoretical cylinder space. These two spaces together make up the clearance. illustrated by the dotted area in Fig. 4. 1. 1-3. The gap between the piston surface and the cylinder head is the linear clearance. its value usually being 0.3-1% of the stroke. The magnitude of the clearance is

$$s_0 A = \varepsilon V_h , \qquad (4-1)$$

where s_0 = clearance, percentage of the stroke; A = working piston surface, m^2; V_h = stroke volume of the cylinder, m^3; (V_h = $A.s$); ε = complete clearance space, percentage of the volume.

The magnitude of the clearance depends on the construction of the cylinder and the permissible gas velocity in the valves and connecting channels. The value of ε in low-speed ($n < 200$/min) horizontal crosshead machines, with discharge pressures up to 10 atm: 6-10%; in low-speed ($n < 200$/min) horizontal crosshead machines, with discharge pressures over 10 atm is between 8-15%; in higher-speed vertical and opposed-piston type machines it is between 10-20%. Greater clearance spaces are permissible in reciprocating compressors working with low compression ratio, the gas delivery change being negligible. In this case the low gas velocities developed in the valves and channels favourably influence the pressure losses and power consumption. Circulating compressors for ammonia synthesis, for instance, are of this sort.

It was assumed in the theoretical diagram in Fig 4. 1. 1-4 that the gas temperature does not change during compression, and that the compression is

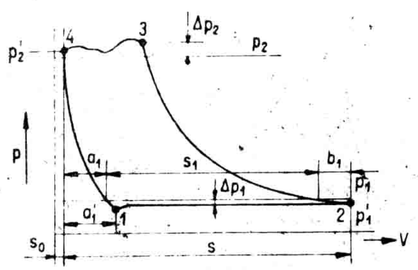

Fig. 4.1.1-4 Actual p-V diagram of the reciprocating compressor

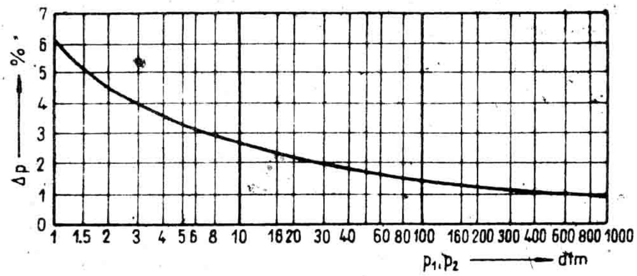

Fig. 4.1.1-5 Pressure drop by suction and delivery pressure as a function of the theoretical pressure

therefore isothermal. In an actual machine the compression is polytropic, as is the expansion of the compressed gas in the clearance space. The suction valves and channels also cause a certain pressure drop, so the suction line in the cylinder falls below the theoretical line. The same applies for the compression, but with reversed sign.

Thus, the area of the diagram increases and the compression work for the same intake gas quantity is greater. The main values of the pressure drop (Δp_1 and Δp_2) for a well-designed machine may be read off as percentage from Fig. 4.1.1-5, as a function of the theoretical suction and final pressure. The expansion of gas in the clearance and the pressure losses reduce the compressor intake to the gas quantity represented by the path s_1 (Fig. 4.1.1-4). The ratio s_1/s is called the volumetric efficiency, or indicated delivery efficiency, λ_i. Its value may be determined from the following relationship:

$$\lambda_i = \eta_v = 1 - \varepsilon \left[\left(\frac{p_2}{p_1} \right)^{\frac{1}{n}} - 1 \right] \qquad (4\text{-}2)$$