Sept. 18, 1962 W. R. CROOKS ET AL 3,054,660

MANUFACTURE OF AMMONIA

Original Filed June 29, 1956

FIG. 1.

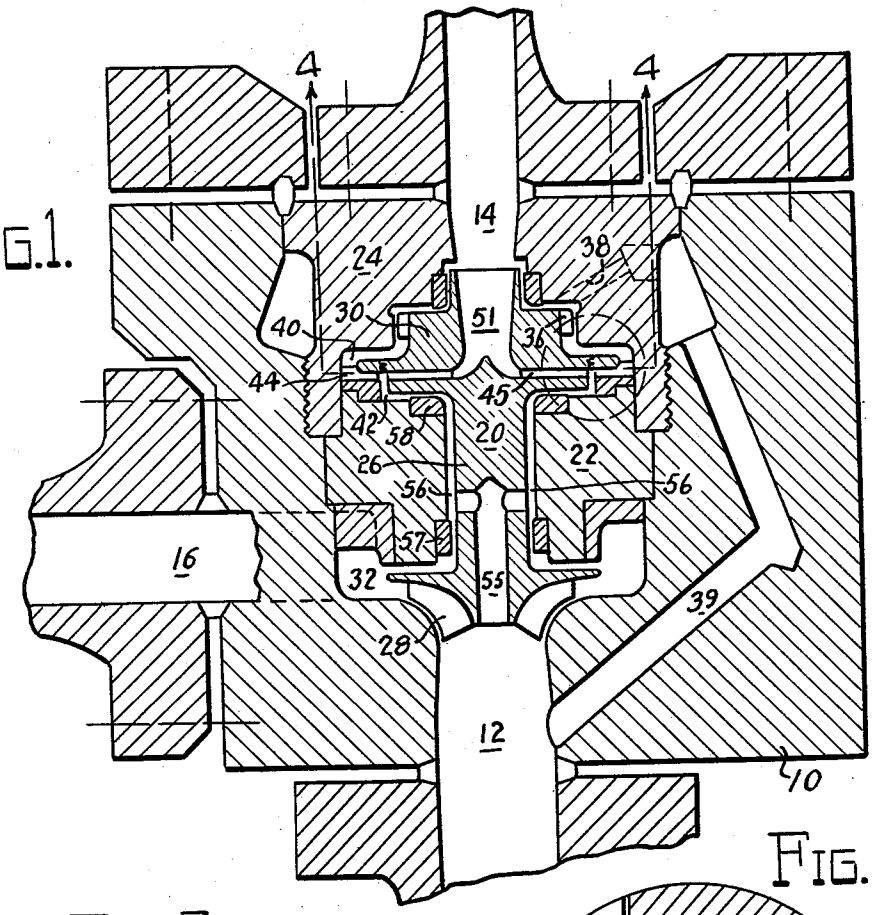


FIG. 2.

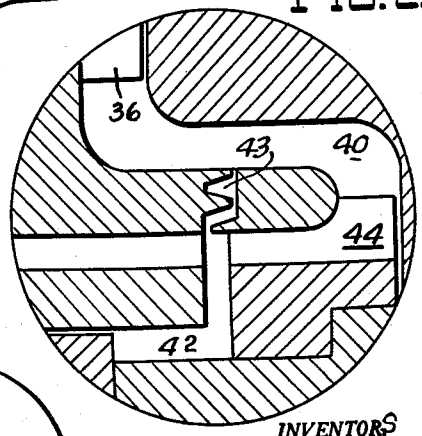
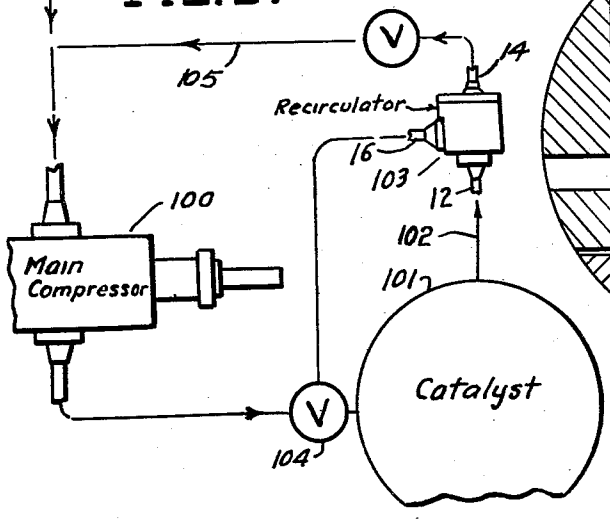


FIG. 3.



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MANUFACTURE OF AMMONIA

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Original application June 29, 1956, Ser. No. 594,808, now Patent No. 2,929,548, dated Mar. 22, 1960. Divided and this application Feb. 17, 1960, Ser. No. 9,240

2 Claims. (Cl. 23—199)

This invention relates to catalytic synthesis of ammonia or the like with the use of a small, high speed turbocompressor.

It has heretofore been considered impractical to build centrifugal compressors in a size range to handle gas flows much below 800 c.f.m. because of excessive gas friction in the narrow impeller passages that are required in so small a unit, and also because the speed of rotation is so high that the lubrication of bearings, gears and couplings becomes a major concern. Further, a centrifugal compressor operating at speeds higher than 20,000 r.p.m. to 30,000 r.p.m. presents a problem in connecting it to a power source, such as an electric motor or an internal combustion engine because it cannot be directly driven, but must be coupled to the power source by gearing or the like which will impart the necessary high rotative speed to the compressor from the low speed prime mover.

Where small flows of air or gas in the order of 15 c.f.m. to 200 c.f.m. are desired at pressure ratios of more than 1.5 to 1, compression has always been accomplished by reciprocating machines. The present invention makes it possible to utilize a rotating machine even for these small flows. The present invention is shown and described herein in an embodiment in which small flows at high pressures are produced.

The present invention provides a process of synthesizing ammonia or the like, which process utilizes a turbocompressor. In such a process, nitrogen and hydrogen are compressed to high pressure, normally from 3000 p.s.i. to 15,000 p.s.i. by means of a multi-stage reciprocating compressor and passed to a catalytic chamber in which a quantity of the gases unite to form ammonia which is taken from the catalytic chamber as a liquid. The free, uncombined gases which have failed to unite in the chamber are taken from it and recirculated. At the present time the recirculation compressors are large reciprocating machines driven by, for example, a 300 horsepower motor or engine. In the synthesis process the gases should be kept from contact with hydrocarbon lubricants since these materials if entrained in the gas stream act to poison the catalyst. This consideration requires that the piston of the reciprocating compressor be supported at its ends by stuffing boxes and held from bearing contact with the walls of the compressor cylinder which can then be operated without lubrication. It will be appreciated that such a recirculation machine is an expensive unit and one that requires very careful maintenance. By utilizing the compressor of the present invention in place of the above described reciprocating machine, the cost of the installation can be reduced to about 5 percent of the cost of the machines now in use, and the possibility of contaminating the gas stream by lubricants can be completely eliminated.

The primary object of the present invention is to improve a process for synthesizing ammonia or the like by utilizing a small, high speed turbine-driven compressor.

Other objects and advantages of the invention will become apparent from the following specification, reference being had to the accompanying drawings, in which—

FIGURE 1 is a central vertical sectional view, somewhat diagrammatic, of a turbocompressor constructed in accordance with the present invention;

FIGURE 2 is an enlargement of the encircled area of the edge of the turbine shown in FIG. 1; and

FIGURE 3 is a diagrammatic view of a circuit in which the turbocompressor is used in a process for the synthesis of ammonia.

In FIGURE 1 of the drawings there is shown a cross-sectional view of a turbocompressor unit that is applicable to the problems involved in the ammonia synthesis process above described. As shown in the drawing, the turbocompressor comprises a housing or body 10 which may be made quite massive to contain gas at several thousand pounds per square inch pressure. The housing is provided with an inlet passage 12, a turbine discharge passage 14 and a compressor discharge passage 16. The housing 10 is provided with a central cavity into which a rotor 20 and a center assembly 22 are inserted from the top, the assembly 22 being split for insertion along a diameter and being retained by an upper retainer 24.

The rotor 20 comprises a central shaft 26 carrying compressor blading 28 at one end and a turbine rotor 30 at the opposite end. The compressor blading may be of any well-known form used for centrifugal compressors and is chosen for the particular compression ratio, mass flow of gas and other conditions for which it is designed. The specific form of the centrifugal compressor does not comprise a part of the present invention and while a single stage compressor is shown a multi-stage compressor may be used as well. Gas taken from the inlet passage 12 enters the blading adjacent the hub and is forced radially outward by the blades into a discharge space 32 which connects tangentially with the compressor discharge conduit 16 in a manner well known in the art.

The turbine rotor 30 at the opposite end of the shaft 26 may include a single stage or a multiplicity of stages. In the form shown, the turbine includes a first impulse stage and a second reaction stage, but this may obviously be varied at the selection of the designer. The impulse stage comprises a series of radial blades 36 extending from the periphery of the rotor and receiving gas from a plurality of circumferentially spaced nozzle openings 38 by which the gas is directed tangentially and downwardly with respect to the blades 36. The supply of gas for the turbine is taken from the compressor inlet passage 12 through one or more side passages 39. The turbine inlet pressure thus approximates closely the compressor inlet pressure in the form shown. It will be apparent that the turbine may be supplied from the compressor discharge passage 16 with equal facility if a higher inlet pressure is desired.

The flow of gas in the impulse stage is in a generally axial direction through the blading so that the first turbine stage formed by the blades 36 discharges into an axial flow discharge chamber 40 which is formed by the periphery of the hub and by an opposed stationary wall of the retainer 24. The rotor of the turbine 30, below the first stage, is provided with a somewhat enlarged flanged portion immediately below the discharge chamber 40 so that the gas is caused to flow outwardly from the center of the rotor into an inlet passage 42 for the second, reaction turbine stage. The inlet passage 42 is formed in a stationary member that is bolted or otherwise fixed to the center assembly 22 so that it is stationary with respect to the rotor. A labyrinth seal 43 is formed on the periphery of the rotor adjacent the stationary member in which the second stage inlet passage is formed. The inlet passage 42 is further provided with guide vanes 44 which direct the gas first downwardly and then radially inwardly into the second turbine stage containing blades 45.

In order to provide the second turbine stage the rotor 30 is formed in upper and lower sections which are subsequently attached into a unitary structure and which are spaced apart by the series of blades between the upper

and lower sections. The upper and lower sections are held together as by rivets 50 which pass through the blades 45 so as to fix the parts in position without introducing the impedance to gas flow of a fastening element. The gas directed from the guide vanes 44 flows into the blading of the second stage, radially inwardly and is discharged into a discharge passage 51 which merges with the axial discharge passage 14.

The entire rotor assembly operates suspended in gas and without frictional engagement with the surrounding stationary wall portions. The present invention provides that the suspending fluid shall have a definite flow pattern, however, and wherever a restriction exists in the flow path a body of material of low dry friction properties is inserted in the stationary housing. This material may be of a graphite, plastic or metallic base, or of any other suitable kind.

Gas for the suspension of the rotor in case of vertical installation is taken originally from the inlet passage 12 into a central passage 55 in the shaft 20 and thence by radial openings into a chamber 56 around the shaft. A lower graphite block 57 separates chamber 56 from the space above the back of the compressor rotor, but the bore of the block has an internal diameter from .003 inch to .005 inch greater than the diameter of the shaft 20. Since the pressure above the back of the compressor rotor will approach the discharge pressure of the compressor, while the pressure in chamber 56 is slightly less than the compressor inlet pressure, the flow of gas around the shaft will always be into the chamber.

The suspension of the rotor and vertical centering thereof is accomplished by the restriction at the underside of the turbine rotor where a second block of heat resistant material 58 is inserted in the center assembly and which separates chamber 56 from the space immediately surrounding the upper portion of the rotor. The gas, at this point, flows radially outward past the stationary block since the pressure in chamber 56 is always higher than the inlet pressure to the second turbine stage. It will be seen that the surface of the graphite block 58 is normally very close to the underside of the turbine rotor, the clearance in practice being only a few thousandths of an inch. For a given set of pressure conditions the spacing between the moving rotor and the stationary block is critical and only one condition of equilibrium will exist. If the rotor should tend to move downwardly and close off the clearance space between the rotor and block the pressure beneath it would rise, tending to restore the rotor to the balanced position. Conversely, if the rotor should tend to move upwardly, the pressure in chamber 56 would tend to drop and cause the rotor to move back into its balanced position. While a vertical orientation of the rotor has been described, it will be apparent that the device will operate in the same manner regardless of the attitude of the shaft. The weight of the rotor is only a few ounces so that bearing loadings would be negligible in comparison to the pressure forces acting on the rotor.

The operation of the turbocompressors so far described can best be understood with reference to a specific set of pressure conditions. In a particular design, the compressor inlet pressure is 2715 p.s.i. and the compressor operation is such that the compressor discharge pressure is 3015 p.s.i. The pressure behind the compressor rotor is slightly less than the discharge pressure and greater than the inlet pressure (which exists in chamber 56) and is approximately 2900 p.s.i. but depends somewhat on the clearance between the bore of the lower heat resistant block 57 and the rotor shaft. It will be noted that the compressor rotor, then, has an upward component of force equal to its projected area times some pressure between the inlet and discharge pressures, as well as a downward component equal to the projected area of the rotor less the area of the rotor shaft and times a pressure slightly less than the discharge pressure. It will thus be apparent that the net effect of the axial pressures on the compressor rotor will be in a direction tending to move the rotor upwardly.

The pressures on the turbine rotor may be summed up algebraically in the same manner, by multiplying the effective area of the upper face of the turbine rotor by the pressure of the gas issuing from the nozzle openings which expands down to about 1920 p.s.i. Beneath the turbine rotor, and thus acting upwardly, the pressure is equal to about 1500 p.s.i. which is the inlet pressure of the second turbine stage, and also acting downwardly is the turbine discharge pressure in conduit 16. The net effect of the axial pressures on the turbine rotor will be in a direction tending to move it downwardly, and the magnitude of the pressures is equal and opposite to the upward pressures developed at the compressor end of the rotor. As above noted, the balance of pressures will be preserved by movement of the rotor to increase or decrease the axial extent of the radial passage formed beneath the turbine rotor and above the block 58, there being a pressure drop of about 1200 p.s.i. across the surface of the block 58 with the parts in normal position.

The rotor is thus free to spin on the gas bearing thus formed and its speed is not limited by the friction inherent in a lubricant film. In the example in which the pressures above set forth occur, the speed of rotation of the rotor is about 48,500 r.p.m., and the maximum diameter of the rotor is 3.75 inches and the compressor input is about 168 c.f.m. of which 38 c.f.m. is diverted in passage 39 to operate the turbine.

It would not be possible to compress such a small quantity of gas efficiently in known compressors with conventional driving mechanisms. While the art is fully conversant with turbine driven compressors used, for example, as superchargers for internal combustion engines, the flow of gas normally occurring in such units is so high that they have never been considered to be applicable to small flow conditions.

An ammonia synthesis process according to the invention is shown in FIG. 3. Accordingly, a plurality of stages of reciprocating compressors are used to raise the pressure of the reactable gases to the desired pressure which usually is about 3000 p.s.i. The last stage of the reciprocating compressor is diagrammatically shown and designated 100 in the drawing and is of conventional form. The gas from the last stage is passed through a catalytic tower 101 in which a variable percentage of the reactable gases combine in the presence of the catalyst to form ammonia which is withdrawn through suitable valves (not shown). The uncombined fraction of the gases is taken from the tower in a line 102 at about 2700 p.s.i. and recirculated. Conventional recirculation compressors are expensive reciprocating machines that are provided with a separate prime mover, usually developing about 300 horsepower. The turbocompressor shown in FIG. 1 is designated 103 in this figure and it will be seen that the compressor intake 12 is connected to the tower 101 while the compressor discharge is connected to a suitable one-way valve 104 to the tower input. The turbine discharge 14 is connected back into the system by a line 105 which conducts the small quantity of gas used in the turbine to an intermediate stage of the reciprocating compressor (not shown) where it re-enters the system. The recirculation is thus accomplished without the addition of a separate prime mover, by deriving energy from the gases that are recirculated, and the spent gases issuing from the turbine exhaust are recovered and recompressed in the system in an intermediate stage.

This is a division of United States application Serial No. 594,808, filed June 29, 1956, for "Turbocompressor," now Patent No. 2,929,548.

Various modifications of the above described embodiment of the invention and, in particular, of the turbocompressor can be made without departing from the scope of the invention, if such modifications are within the spirit and tenor of the appended claims.

We claim:

1. A method of making ammonia by synthesis of its component gases which comprises compressing gases in a reciprocating compressor, passing said compressed gases through a chamber containing a catalyst, wherein some of said gases combine, withdrawing from said chamber the combined gases in the form of ammonia, removing from said chamber the fraction of compressed gases that remain uncombined, expanding a portion of said uncombined, removed gases in a turbine, utilizing part of the energy of the expanded gases to drive a centrifugal compressor, and passing the remainder of said uncombined, removed gases through said centrifugal compressor and back into said catalytic chamber.

2. A method of making ammonia by synthesis of its component gases which comprises compressing gases in a reciprocating compressor, passing said compressed gases through a chamber containing a catalyst, wherein some

of said gases combine, withdrawing from said chamber the combined gases in the form of ammonia, removing from said chamber the fraction of compressed gases that remain uncombined, expanding a portion of said uncombined, removed gases in a turbine, utilizing part of the energy of the expanded gases to drive a centrifugal compressor, passing the portion of said gas from which energy has been removed back to the reciprocating compressor, and passing the remainder of said uncombined, removed gases through said centrifugal compressor and back into said catalytic chamber.

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