H. A. HUMPHREY.

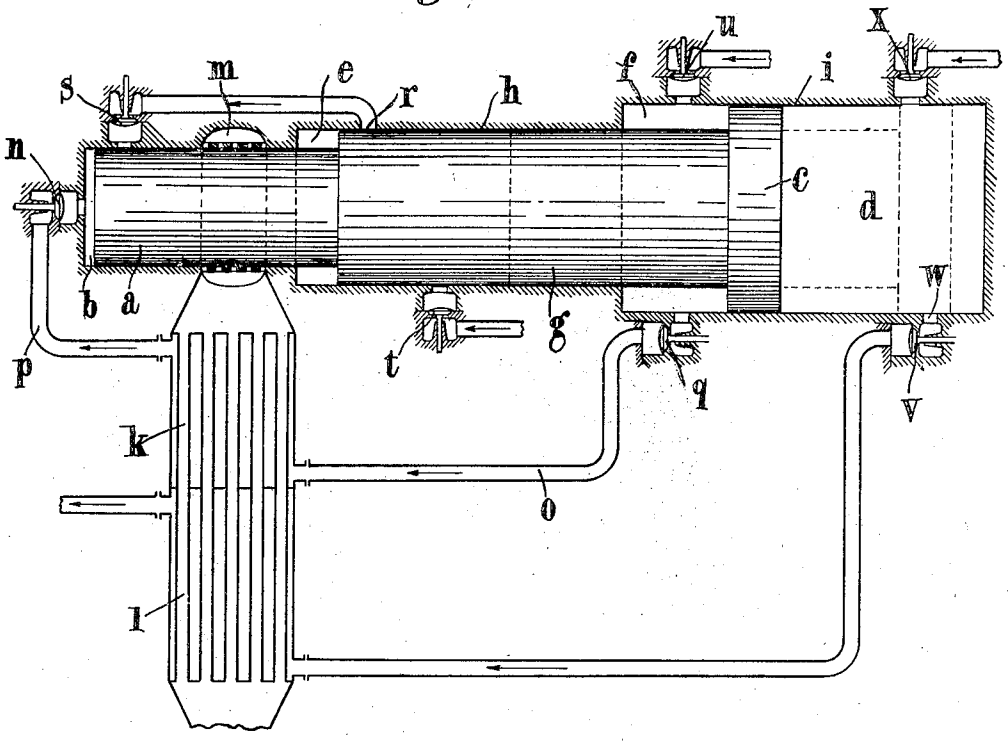
APPARATUS FOR PRODUCING NITRIC OXIDE.

APPLICATION FILED DEC. 18, 1918.

1,429,035. Patented Sept. 12, 1922.

2 SHEETS—SHEET 1.

Fig. 1.



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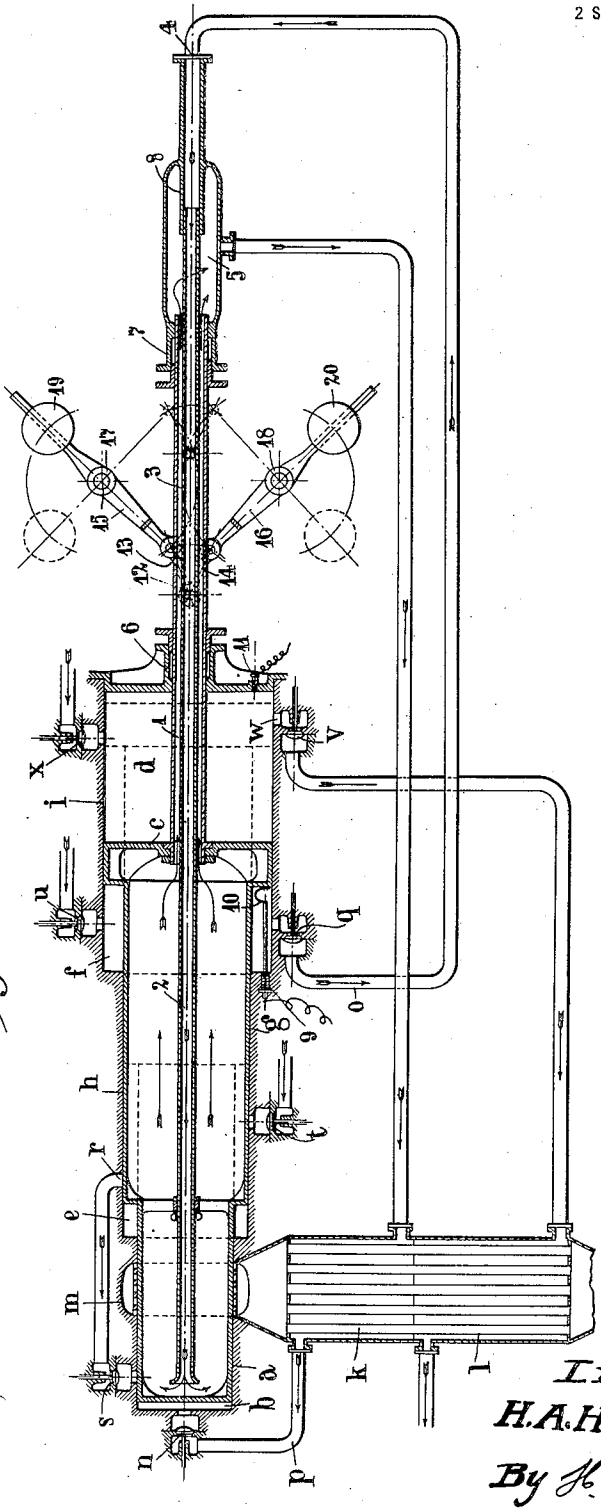


Fig. 2.

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Patented Sept. 12, 1922. 1,429,035

UNITED STATES PATENT OFFICE.

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APPARATUS FOR PRODUCING NITRIC OXIDE.

Application filed December 18, 1918. Serial No. 267,369.

To all whom it may concern:

Be it known that I, HERBERT ALFRED HUMPHREY, a subject of the King of Great Britain and Ireland, and residing at The Munitions Inventions Department Research Laboratory, University College, Gower Place, London, W. C. 1, England, have invented a certain new and useful Improved Apparatus for Producing Nitric Oxide, of which the following is a specification.

This invention relates to an apparatus for the production of nitric oxide by igniting an explosive gaseous mixture containing nitrogen and oxygen under suitable conditions so that the rise of temperature is sufficient to cause a portion of these two gases to combine in order to form nitric oxide.

As the result of my experience I have ascertained that in order that such a process may result in a high yield of nitric oxide, the following conditions should, as far as possible, be fulfilled, namely:—

(1) The gaseous constituents should be measured and correctly proportioned and the mixed combustible gases should be preheated before ignition to as high a degree as possible and preferably to such a point that the mixture will ignite during compression.

(2) The highest possible temperature should be attained during the process.

(3) Subsequent to the attainment of the maximum temperature the gases should be cooled as rapidly as possible, both by expansion and by the performance of external work, so that the nitric oxide formed may be prevented from undergoing decomposition while passing through the range of temperatures at which decomposition tends to take place.

(4) The process should be carried out under such conditions that the combustible mixture may not be diluted with inert gases, such as carbon dioxide and water vapour, but may possess the maximum heat value per unit volume.

It has been hitherto proposed to carry out a process of the kind referred to in the cylinder of an ordinary gas engine with a view to the simultaneous production of power, but having regard to the necessity for the fulfillment of the above conditions a gas engine such as is ordinarily employed, in which the piston is controlled by a flywheel and connecting rod, is unsuitable for the purpose.

The object of the present invention is to provide an improved method of and apparatus for the production of nitric oxide, whereby the optimum conditions may be closely approximated and the yield from the process materially increased, and the invention consists in a process for producing nitric oxide according to which an explosive mixture containing nitrogen and oxygen in suitable proportions is ignited in a confined space produced by a partition or member which is freely movable by the expansion of the gases following upon ignition, the supply of gases to, and the exhaust from, the combustion space being controlled by suitable means.

The invention also embraces apparatus for carrying out the above process, comprising a cylinder of differential diameters and having admission and exhaust ports, and a freely movable piston of corresponding differential diameters within said cylinder and adapted to control said ports.

The invention also embraces the method of and apparatus for producing nitric oxide hereinafter more particularly described.

Figure 1 is a diagrammatic elevation partly in section showing one form of apparatus in accordance with the invention.

Figure 2 is a similar view showing the parts in greater detail and in part sectional elevation.

In carrying my invention into effect in the manner illustrated, I provide a piston having differential diameters and arrange the same to reciprocate within a cylinder constructed to form a series of coaxial portions of corresponding differential diameters, the arrangement being such that the movements of the piston are conditioned only by work done and energy stored and also by the use of elastic cushions.

Where it is desired that the apparatus should be self-contained and adapted to measure, compress and supply its own combustible gas and scavenging air, I may construct the piston and cylinder with three differential diameters, as shown, one end *a* of the piston being adapted to be acted upon by the explosive gases within the cylinder *b*, and the other end *c* to compress in the chamber *d* an elastic fluid which in turn performs useful external work, intermediate annular spaces *e f* being formed by the movements of the central piston *g* within the differential cylinders *h i*.

The annular space *e* may serve to take in and supply to the combustion cylinder *b* the combustible constituents, preferably in such proportions that the mixture will not ignite until mixed in the combustion space with a combustion supporter, such as air, supplied from the second annular space *f*.

The inlets and outlets in the various parts of the cylinder may be covered and uncovered in appropriate sequence by the piston during its movements within the cylinder, thus permitting of the employment of simple spring-controlled check valves in the passages communicating with such inlets and outlets.

When the apparatus operates upon the two-stroke cycle, the return stroke following a power stroke is effected by means of energy stored in one or more elastic cushions which are preferably made variable in capacity for purposes of control.

One or more of the combustible constituents is or are preferably preheated to as high a degree as possible, and this may be effected by causing the same to pass through a suitable heat interchanger or re-heater *k l* by which they may abstract some of the sensible heat from the burnt products passing from the cylinder *b* through a large exhaust port *m* and a portion of such sensible heat may also be used to heat the compressed air or other gas passing from the chamber *d* before the gas is used for power purposes.

The scavenging of the apparatus must be as complete as possible in order to prevent the combustible mixture from becoming diluted with inert gases, such as CO_2 and H_2O, and the scavenging air and/or one or more of the combustible constituents may be compressed or stored under pressure during one stroke in order to be employed during the succeeding stroke.

As shown in Fig. 2 the connected pistons *a*, *g*, *c*, have rigidly attached to them, tubes 1 and 2, of which the tube 1 is larger than the tube 2 so that there is provided an annular space 3 between them by means of which the heated air which has cooled the pistons can find an exit.

The cold air enters at 4 and passing to the splayed end of the tube 2 impinges upon the hottest part of the piston *a*, flows through the interior of the pistons *a*, *g*, and *c* in sequence and finally passes out through the annular space 3.

The tube 1 slides in stuffing boxes 6 and 7 and the tube 2 slides in the pipe 8, thus providing a closed pipe circuit for the scavenging air and permitting this air to receive its first pre-heat before it enters the heater 1 where it is subsequently further re-heated.

The operation of the apparatus shown is as follows:—Assuming that the piston *a* is at the end of its stroke to the left and behind the piston is a compressed charge of explosive mixture, the charge is ignited by an electric spark in a manner to be described later and, the valve *n* being shut, the piston is driven under high pressure to the right. The gases expand until the left hand end of the piston *a* reaches the exhaust port *m*; this being a large port, the pressure falls rapidly and the exhaust gases passing downward through the tubular re-heater *k l* and so to the absorption apparatus where the nitric oxide is recovered. As soon as the pressure has fallen sufficiently, scavenging air stored under slight pressure in the pipe system *o p*, between the valves *n* and *q*, opens the valve *n* thus sweeping the exhaust gases towards port *m*, the piston then completing its movement towards the right.

On the piston returning towards the left, air is compressed in the chamber *f* and delivered past the valve *q* through the top half *k* of the tubular re-heater into the chamber *b* and a little later the rich gas mixture from *e*, now under some pressure, is forced through the port *r* and valve *s* to mix with the hot air in the chamber *b*. The piston by its movement now closes the port *m* and compresses the explosive mixture, the ignition of which commences a fresh cycle.

Dealing with the operation in the cylinder *h*, the piston in travelling to the right takes in a rich gas mixture through the inlet valve *t* and then on its return stroke to the left acts as a pump, pumping this mixture through the port *r* and valve *s* into the chamber *b*. The exact pressure at which the valve is opened may be determined by a spring on this valve.

When the port *m* is closed by the piston *a*, since the length of the remaining space in the cylinder *h* is greater than the remaining space in the chamber *b* the pressure in *b* rises faster than in *e* and valve *s* closes.

Chamber *f* with its piston *c* constitutes an ordinary air pump and while the piston is travelling to the right air is drawn into the annular space *f*, past the non-return valve *u*, and when the piston travels to the left this air is delivered past the valve *q* through the re-heater *k* into the chamber *b* so long as port *m* is open. When this port closes, the pressure in *b* rises more quickly (due to the ratio of clearance spaces) than the pressure in *f*, so that valve *n* immediately shuts and the only effect of the piston travelling further to the left is to store air under some pressure in the pipe system between valves *q* and *n*.

Considering now the operation in the chamber *d* when the piston moves to the right, air is compressed and then delivered past the non-return valve *v* to the air pressure storage vessel (not shown). This delivery is cut off when the piston closes the port *w* and from this point the air is further compressed into the closed space at the

end of *d* until the kinetic energy of the moving piston is absorbed in raising the pressure of the enclosed air, thus bringing the piston to rest. The energy in this compressed air starts the piston in its movement to the left again and imparts momentum to it until the air in the chamber *d* has expanded to atmospheric pressure. From this point the further travel of the piston draws in fresh air through the inlet valve *x* during the remainder of the stroke.

Further in connection with the operation in chamber *d* it may be stated that the volume of air compressed in this chamber by the piston *c* after the latter closes the port *w* is sufficient to absorb the remaining energy (mainly kinetic energy of the moving piston mass) without exceeding a desired maximum pressure in *d*. Moreover any air volume remaining in chamber *d* after port *w* is closed, is theoretically capable of absorbing (and returning again) any energy remaining in the system. If the volume is relatively small the pressure reached will be relatively high and vice versa. Finally, during the movement of the piston to the left, no expansive force is lost by escape of air through valve *v*, since said valve does not open after the head *c* passes the port *w*. On expansion when *c* uncovers *w* on moving to the left, the pressure will have fallen back at least to the same point where it stood in the movement of the piston to the right. Therefore, the pressure in *d* at this point of time cannot exceed that on the delivery side of the valve *v* and consequently this valve will not open.

In the drawing the compressed air is shown as passing through the heat-regenerator *l*, but this merely indicates that a portion of the heat of the exhaust gas is used to increase the volume of the compressed air used for power. This air, however, should be heated after storage and on its way to the compressed air motors.

It will be observed that safety cushions exist in all the cylinders but more especially in the left hand end of chamber *b* and the right hand of chamber *d*. These ensure the bringing of the piston to rest.

The apparatus is started by bringing the piston into such a position that it is about at its mid-stroke and then pumping into chamber *b* by hand an explosive mixture which is hand fired (electrically) so as to give the piston an initial movement to the right and to compress the elastic cushion in the end of the chamber *d*. The small inlet and outlet in the chamber *b* necessary for this are not shown in the drawing. It may be necessary to hold open the inlet valve *x* during the first stroke to the right, but the action of the apparatus thereafter becomes automatic.

The speed of operation is controlled principally by the weight of the piston (per unit area) and the equilibrium among the various indicator diagrams is obtained by the proper proportioning of the sizes of the cylinders and the clearance spaces in the cylinders *b* and *d*.

A corresponding problem of this nature has been worked out in connection with the solid piston Humphrey pump, and pumps of this character are operated with a free heavy piston at speeds from 60 to 250 cycles per minute, according to size. The mechanical problems do not, therefore, greatly differ in kind from existing apparatus.

It should be understood that the acceleration of the piston when first moving to the right is very great, while the high pressure gases act upon it. Expansion is, therefore, more rapid than is possible in a gas engine where the piston travel has to conform with the movement of a crank and flywheel. The slowest part of the movement occurs towards the end of the travel of the piston to the right and this gives time for the scavenging gases to be passed through at a comparatively low pressure. Electrical ignition is secured by a contact device preferably placed in the cylinder *f* which is cold.

In the form of apparatus illustrated, 9 represents an insulated plug adjustable axially by hand-wheel and screw, and 10 is a flexible metallic spring making contact with 9 when the pistons have moved far enough to the left. The binding screw 11 and the spring 10 are both electrically in contact with the metal parts of the apparatus and the circuit containing the sparking plug which fires the mixture in space *b* is contained between 9 and 11, hence the circuit is completed when 9 and 10 make contact thus causing a spark in space *b* and sparking may be advanced or retarded by rotating the hand-wheel which adjust the contact 9. The spark is produced in the cylinder *b* somewhat before the end of the stroke, thus giving the maximum possible explosion temperature. Where the gases are preheated before compression, ignition (and pre-ignition) may become spontaneous.

Where variable cushion capacity is provided such capacity may conveniently be constituted in one or more vessels capable of sustaining the required pressure and connected to such cylinder or part of the main apparatus where the cushion is acted upon by the piston. Since the pressure to which the elastic cushion is raised by a given movement of the piston depends on the total cushion capacity the control of the movements of the piston will partly depend on this capacity which may be automatically varied by pumping in or evacuating liquid which thus displaces more or less of the elastic medium.

Pivoted to the tube 1 at 12 are two links 13 and 14 which serve to connect the levers 15 and 16 which are respectively pivoted at 17 and 18. The pivots at 17 and 18 are rigidly carried from the frame of the apparatus and form the stationary centres about which the levers 15 and 16 oscillate as the pistons and tube 1 reciprocate. Attached to 15 and 16 are weights 19 and 20 which are adjustable in position on the levers and capable of being fixed in any desired position along their respective levers. These weights add to the reciprocating masses and the inertia so added will be greater as the adjustable weights are shifted further from their respective pivots 17 and 18. This system of linked weights therefore forms a means of adjusting the total inertia of the reciprocating system with the result that the speed of reciprocation of the apparatus may be controlled.

It is not considered necessary to describe in greater detail variable cushions or arrangements of linked weights because they are known from British Patents Nos. 11818 and 28187 of 1911.

Investigation has shown that a higher yield of nitric oxide is obtained as the concentrations of nitrogen and oxygen in the exhaust products approach a maximum thus indicating that the employment of oxygen to replace some or all of the air will give greater yields of NO. A rich gas is very much more effective than a poor gas and quite out of proportion to the ratio of their calorific values. The method and apparatus is specially useful in combination with a process yielding oxygen as a waste product for the utilization of a supply of oxygen would give the maximum yield of NO with the present method.

It is to be understood that the foregoing details of construction are given by way of example only, as I may form the apparatus such that the conversion only into nitric oxide will be performed therein, the measuring and compressing of the constituents being effected by external means, and the shape and formation of piston and cylinder and the means of controlling the inlet and outlet of gases may be suitably modified according to any particular practical requirements that may have to be fulfilled.

Having now described my invention, what I claim as new and desire to secure by Letters Patent is:—

1. Apparatus for the production of nitric oxide, comprising in combination a cylinder of differential diameters and having admission and exhaust ports, and a movable piston of corresponding diameters within said cylinder and adapted to control the said ports.

2. In the apparatus claimed in claim 1, the arrangement of a second co-axial cylinder and an extension of the piston therein having a different diameter from the combustion cylinder and piston and so constructed as to act as a pump for combustible mixture or a constituent thereof.

3. In the apparatus claimed in claim 1 the arrangement of a co-axial extension of the cylinder and piston having a different diameter from those mentioned in claim 1 and so constructed as to act on one side of the piston as a pump for scavenging air and on the other side of the piston as a compressor of elastic fluid.

4. In the apparatus claimed in claim 1, suitable ports in the differential cylinders adapted to be covered and uncovered by the piston so as to permit the functions of the respective cylinders.

5. In the apparatus claimed in claim 1, a heat interchanger adapted to exchange heat between the exhaust gases and the scavenging air.

6. In the apparatus claimed in claim 1, means of controlling the functioning by the aid of linked weights having adjustable moments of inertia about their rocking centres.

In testimony whereof I have signed my name to this specification.

HERBERT ALFRED HUMPHREY.