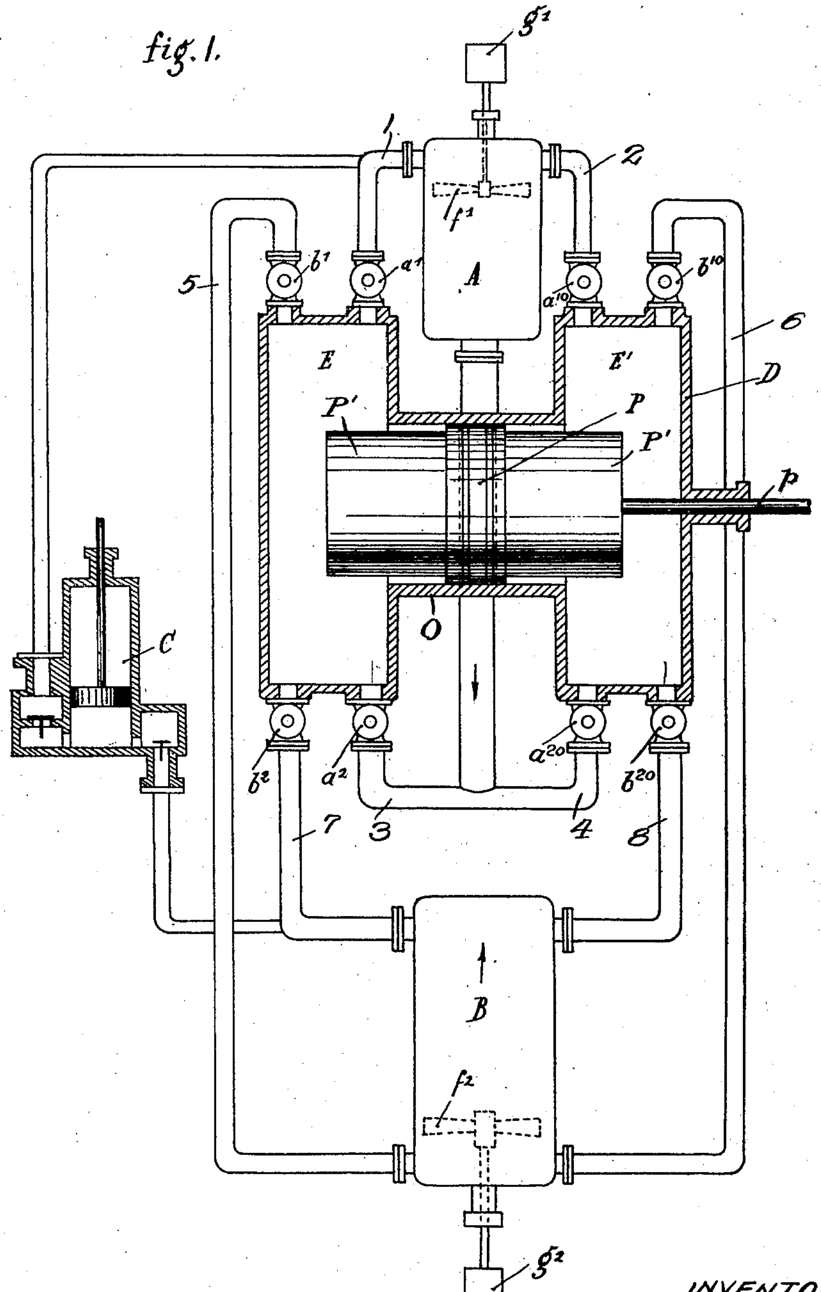
C. L. A. M. LEBLANC

MACHINE FOR AND METHOD OF REFRIGERATING

Filed Sept. 22, 1921 5 Sheets-Sheet 1

Fig. 1.



INVENTOR

C. L. A. M. Leblanc

by Green & McCallister

his Attorneys in fact.

May 11, 1926. **1,584,382**

C. L. A. M. LEBLANC

MACHINE FOR AND METHOD OF REFRIGERATING

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fig. 3.

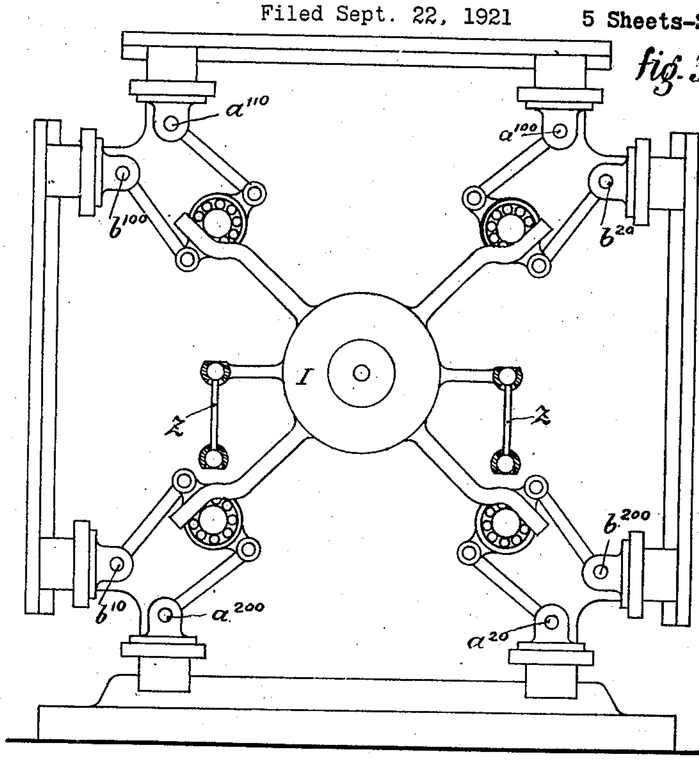
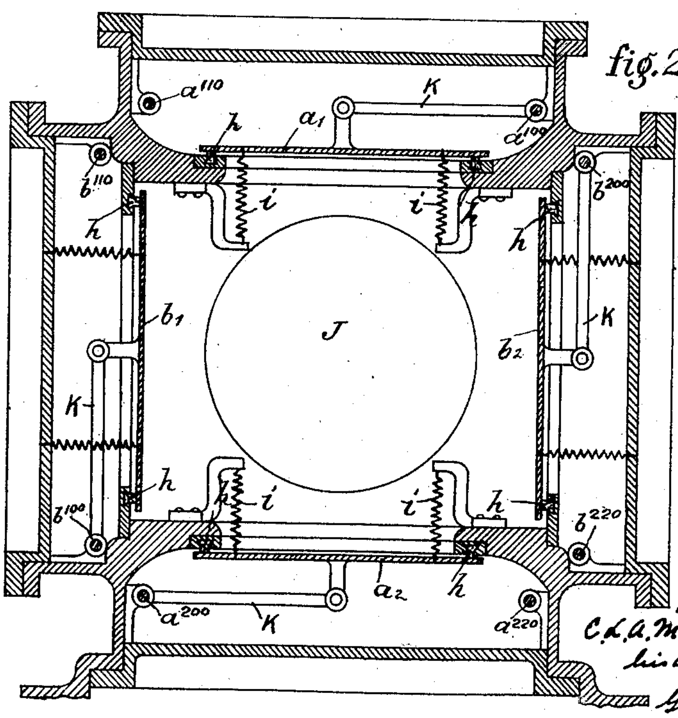


fig. 2.



INVENTOR

C. L. A. M. Leblanc, by his attorneys -

Green & McCallister

May 11, 1926. 1,584,382

C. L. A. M. LEBLANC

MACHINE FOR AND METHOD OF REFRIGERATING

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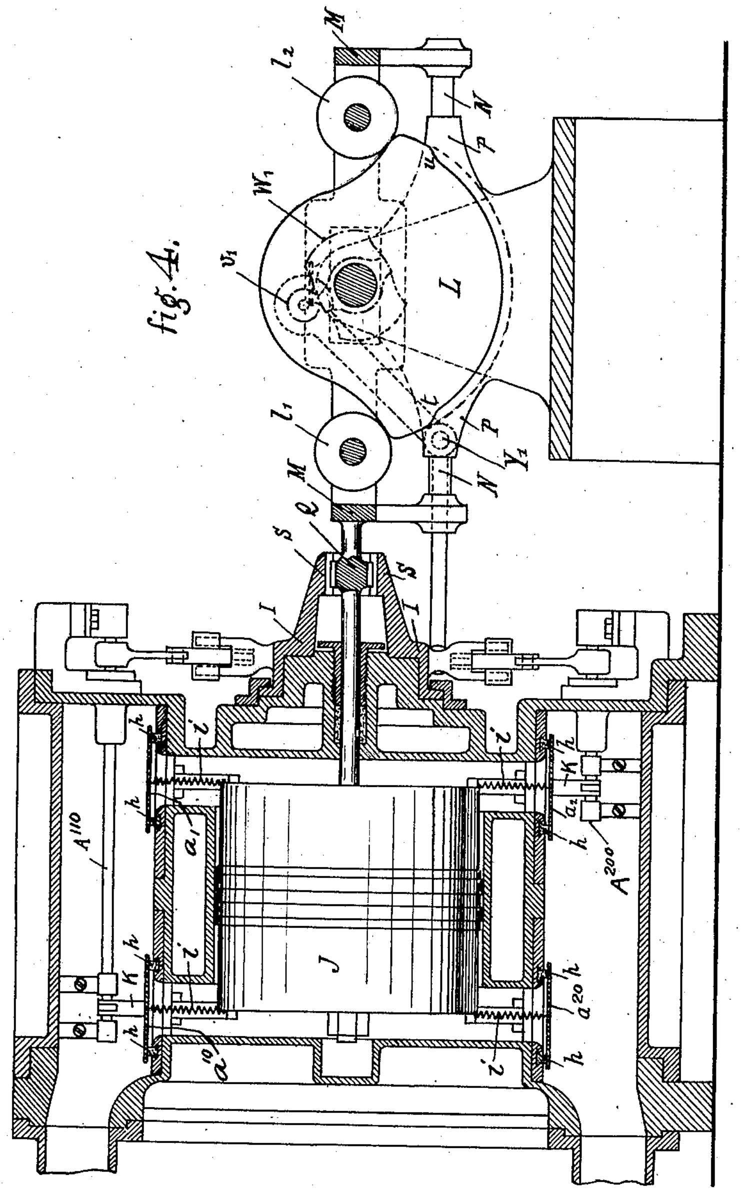

INVENTOR

C. L. A. M. Leblanc

by Green & McCallister

his attorneys in fact.

May 11, 1926.

C. L. A. M. LEBLANC

1,584,382

MACHINE FOR AND METHOD OF REFRIGERATING

Filed Sept. 22, 1921

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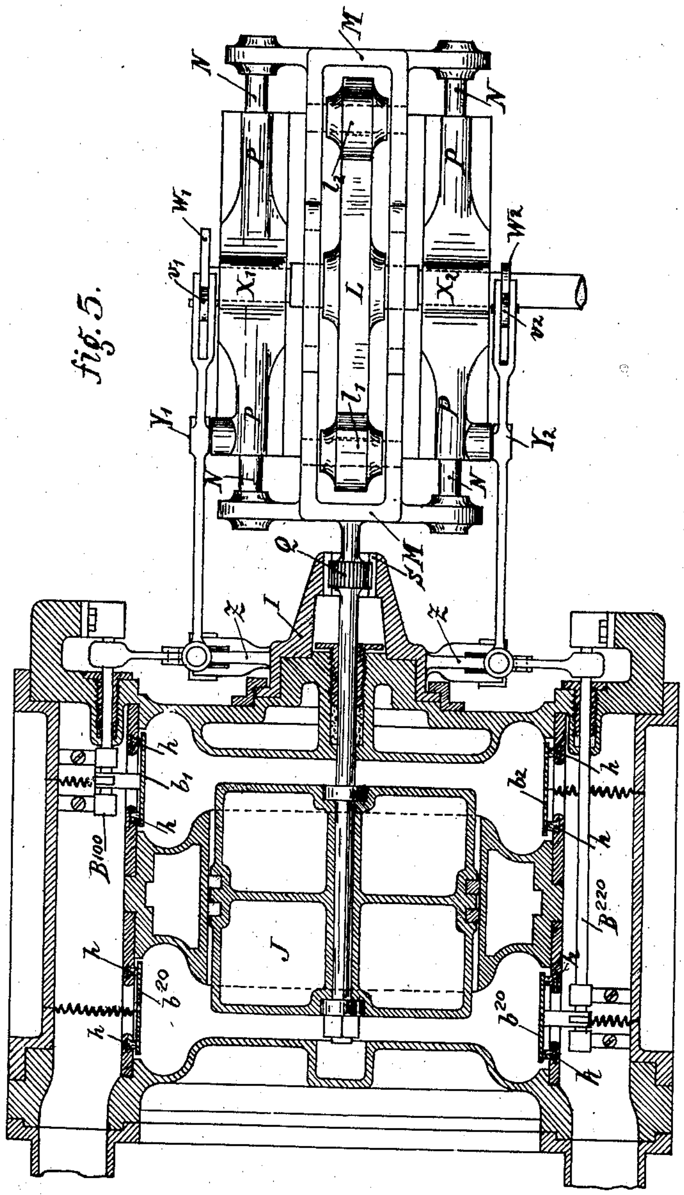
Fig. 5.



INVENTOR

C. L. A. M. Leblanc,

by Green & McCallister

his attorneys in fact.

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C. L. A. M. LEBLANC

MACHINE FOR AND METHOD OF REFRIGERATING

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fig. 6.

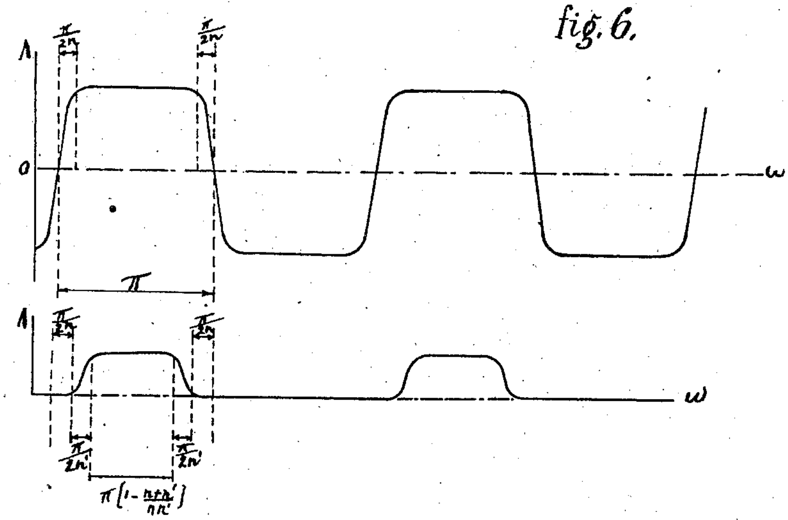


fig. 7.

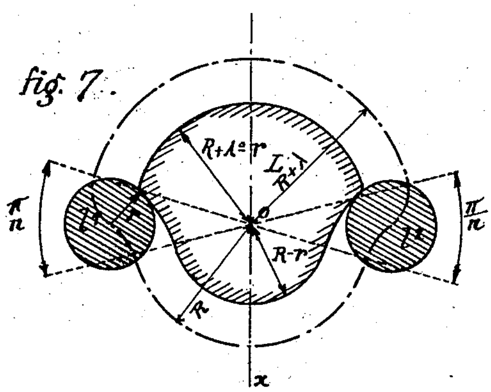


fig. 8.

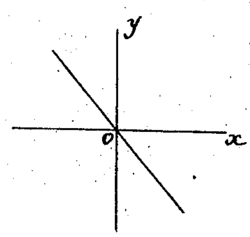


fig. 9.

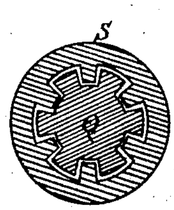


fig. 10.

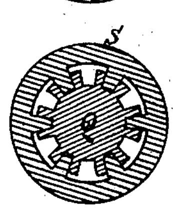
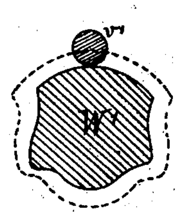


fig. 11.



INVENTOR

C. L. A. M. Leblanc

by Green & McCallister,

his attorneys in fact.

Patented May 11, 1926. 1,584,382

UNITED STATES PATENT OFFICE.

CHARLES LÉONARD ARMAND MAURICE LEBLANC, OF PARIS, FRANCE, ASSIGNOR TO SOCIÉTÉ ANONYME POUR L'EXPLOITATION DES PROCÉDÉS MAURICE LEBLANC-VICKERS, OF PARIS, FRANCE.

MACHINE FOR AND METHOD OF REFRIGERATING.

Application filed September 22, 1921. Serial No. 502,508.

The invention relates to refrigerating machines and has particular relation to the type in which a gas, such as air, is first compressed, causing it to rise in temperature, then circulated through a cooling device under pressure in order to lower its temperature, then to expand the cooling gas to cause it to lower still further in temperature, and finally to circulate the gas through the refrigerator at a pressure substantially equal to the internal pressure of the refrigerator, from whence it is withdrawn and again subjected to the cycle of operations outlined above.

One of the objects of the present invention is to provide a machine, of the character described, which embodies a double acting compressor and expander that will first compress a body of gas delivered thereto from a refrigerator, thereby causing its temperature to rise; then to subject the gas under pressure to the action of a cooler and at the same time replacing it by gas from the cooler which is under the same pressure but of a lower temperature; then expanding this cold gas to further reduce its temperature; then to deliver this latter body of cold gas to the refrigerator from which it originally issued and replacing it in the expander by the warm air displaced thereby in the refrigerator.

Another object of the invention is to provide a machine, of the class designated, which embodies an auxiliary compressor which is adapted to supplement the volume of gas within the cooling device in order to compensate for the decrease in the volume thereof caused by the cooling action of said device.

A further object of the invention is to provide a machine of the class described which is of light weight, relatively simple in construction and operation, and which may be operated with a relatively small expenditure of power.

With such objects in view, as well as other advantages which may be incident to the use of the improvements, the invention consists in the procedure and in the use of the parts and combinations thereof hereinafter set forth and claimed, with the understanding that the several necessary elements constituting the same may be varied in proportions and arrangement without departing from the nature and scope of the invention.

In order to make the invention more clearly understood there are shown in the accompanying drawings means for carrying the same into practical effect, without limiting the improvements, in their useful applications, to the particular constructions which, for the purpose of explanation, have been made the subject of illustration. In the said drawings:—

Fig. 1 represents diagrammatically a refrigerating machine using air in accordance with the invention.

Fig. 2 shows in transverse section one of the compression or expansion spaces or chambers of the main compressor.

Fig. 3 is an end view as seen from right to left of the said compressor showing the control mechanism of the distribution valves of the said compressor.

Fig. 4 is a vertical longitudinal section through the axis of the main compressor, showing the control mechanisms of the piston and the distribution valves.

Fig. 5 is a horizontal longitudinal section through the axis of the said compressor showing the same mechanisms.

Fig. 6 is a diagram showing the variation of the lift of the distribution values of the compressor in relation to the angle of rotation *w* of the control shaft of the main compressor.

Fig. 7 shows the profile of the cam controlling the alternating movement of the main compressor.

Fig. 8 is a diagram showing the variation of the differences of pressure supported by the piston of the main compressor as a function of its displacement, having for origin the mean position of the piston.

Figs. 9 and 10 are transverse sections of the arrangement of piston stop in two distinct angular positions.

Fig. 11 shows the profile of the cams controlling the mechanism actuating the valve of the main compressor.

In the following description the letters P V and T designate the pressure of the air, its specific volume and its absolute temperature. If these quantities have the values P_x, V_y, T_z, the air is said to be in the state P_x, V_y, T_z.

According to the invention, for the purpose of obtaining the described cycle of circulation, there is illustrated a refrigerating machine which comprises in general, a cooling device A, a refrigerator B, a main compressor and expander D, and an auxiliary compressor C, which latter is adapted to draw per kg. of gas describing the cycle, a volume V_3—V_2 at the pressure P_2 from the refrigerator B and to transfer it to the cooling device A. The main compressor and expander D consists of a cylinder O which communicates at each end with chambers E and E′. An intermittently operable double acting piston P is mounted within the cylinder O and is reciprocated by means of a piston rod which is in turn reciprocated by means of mechanism hereinafter to be described.

The piston P is provided with oppositely extending plungers P′ which are adapted to alternately enter the chambers E and E′ to vary the cubical contents thereof in the ratio $\frac{V_2}{V_1}$.

Each of these chambers E and E′ is provided with four distributing valves which consist of slides or taps of suitable construction.

The distributing valves of the chamber E are designated at a^1, a^2, b^1, b^2, and those of the chamber E′ at a^{10}, a^{20}, b^{10}, b^{20}. The distributing valves a^1 and a^{10} communicate with the inlet of the cooler A through pipes 1 and 2 respectively, and the distributing valves a^2 and a^{20} with its outlet through pipes 3 and 4. The distributing valves b^1, b^{10} communicate with the inlet of the refrigerator B, through pipes 5 and 6 respectively, and the distributing valves b^2, b^{20} with its outlet through pipes 7 and 8.

All the distributing valves being closed, the piston moves rapidly from one end of its stroke to the other and dwells there; assuming that such dwell occurs within the chamber E.

At this moment the chamber E is full of air under pressure in the state P_1 V_4 T_4. The chamber E′ is filled with relatively rarefied air in the state P_2 V_2 T_2.

The distributing valves a^1, a^2, b^{10}, b^{20} open quickly and remain open.

Fans f^1, f^2, actuated by motors g^1, g^2 cause air currents which impel: (1) the air in the chamber E at pressure P_1 and temperature T_4, sending it into the cooler and replacing it, in this chamber by air at pressure P_1, but at temperature T_1 coming from the cooler; (2) the air in the chamber E′ at pressure P_2 and temperature T_2, sending it into the refrigerator and replacing it in this space by air at pressure P_2 but at temperature T_3 arriving from the refrigerator.

In replacing a volume of air at the temperature T_4 by an equal volume of air at the temperature T_1 the amount of air contained in the chamber E is multiplied by $\frac{T_4}{T_1}$. Similarly in replacing a volume of air at temperature T_2 by an equal volume of air at temperature T_3 the amount of air contained in the chamber E′ is divided by $\frac{T_3}{T_2}$. Moreover,

$$\frac{T_4}{T_1}=\frac{T_3}{T_2}.$$

The result is that the main compressor D forces a larger volume of air into the cooler than is returned to the compressor therefrom, but the volume of air thus lost will be supplemented in the refrigerator by the auxiliary compressor C which will return it into the cooler.

Once the impelling is effected, the open distributing valves a^1, a^2, b^{10} and b^{20} are rapidly closed whereupon the piston moves quickly to the other end of its stroke where it also dwells within the chamber E′. It is now the distributing valves b^1, b^2, a^{10}, and a^{20} which open.

The diagram given by a Watt's indicator taken on one face of the piston of the main compressor D is reduced to a simple adiabatic line (P_1 V_1 T_1—P_2 V_2 T_2), successively traversed in opposite directions. Its area will then be nil.

The compressor C requires no description since it possesses no particular features and may consist of any ordinary compressor.

As regards the main compressor D, in order to make it function, its inherent resistances must be overcome and the fans operated.

It will be seen from the following that these inherent resistances are all naturally much reduced by reason of the operation itself. It may be said with high approximation that the work absorbed thereby is proportional at each instant to the work imparted to or taken from the air by the piston.

But the apparatus being double-acting the difference of the pressures supported by the piston will change sign when the latter reaches the middle of its stroke. In the first part it will take up a quantity of work which it will restore to the air during the second half.

The main compressor D may be of a variety of forms but the following is recommended:—

To facilitate the impelling a square section is given to each of the chambers E and E′ the volume of which is varied by the piston plungers. One of these chambers is represented in section at right angles to the axis of the piston on Fig. 2.

The distribution valves a^1, a^2, b^1, and b^2 consist of plates. The plates a^1 and a^2 are situated face to face and occupy substantially all of the space on the two opposite sides of the chamber under consideration and which are supported on their respective valve seats. The valves b^1 and b^2 are similarly mounted on the two other sides of the chamber.

The pressure in the chambers being always less than that of the cooler, the plates a^1 and a^2 which connect them together, are arranged as exit valves. The pressure in the space being always greater than that of the refrigerator, the valves b^1 and b^2 which place these in communication are arranged as inlet valves.

These valves consist of metallic plates and their seatings preferably comprise a soft packing h of rubber (Fig. 2).

The several plates are pressed on their seatings h by means of springs i and are opened by levers K which control the distribution system of Fig. 3.

In Figs. 2 and 3 the fulcrums of the levers K which control the valves of the chamber E referred to and those of the chamber of the main compressor D are designated by the a^{100}, a^{200}, b^{100}, b^{200}, a^{110}, a^{220}, b^{110}, b^{220}.

Sets of levers shown in Fig. 3 determine the movement of the valves a^1, a^2, b^{10}, b^{20} and those of the valves b^1, b^2, a^{10}, a^{20}. The control of this mechanism is obtained from the shaft of the motor which actuates the whole machine by means of an arrangement hereinafter explained in detail.

The impelling system will cost much less if the valves are of large section, are opened more rapidly and if more time is given for effecting it.

The arrangements adopted permit of a very large section being given to the valves.

A diagram is drawn having as abscissæ the angle w through which the main compressor D will have turned and as ordinates the distance through which the piston will be displaced from its mean position (Fig. 6). It will be brought as quickly as possible from one end of its stroke to the other while the machine turns $\frac{\pi}{n}$. It is then left motionless until the machine has turned anew through an angle equal to

$$\frac{n-1}{n}\pi.$$

The variations of the distance Λ in relation to the angle w are represented by the upper curve of Fig. 6.

At the moment when the piston stops the valves commence to open and while they are opening the machine will turn through an angle

$$\frac{\pi}{2n'}.$$

The variations of the height to which a given valve will be raised as a function of the angle w are represented by the lower curve of Fig. 6.

Each valve will be partly open while the machine is turning through an angle

$$\frac{\pi}{n'}$$

and fully open when turning through an angle

$$\pi\left(1-\frac{n+n'}{nn'}\right)$$

and this once every turn.

The aim is to operate the piston and valves rapidly so that these will remain fully open as long as possible.

It will be observed in passing, that from the moment when the piston is very quickly brought from one end of its stroke to the other and then temporarily rendered inactive it is necessary to supply it with work during the period when the motor will supply it most often in a continuous manner. This work should therefore be first stored in a flywheel to be next given back quickly. This operation not being possible without loss it is desirable to render as small as possible the work absorbed by the piston. This is one of the reasons why the machine has been divided up and instead of using a single acting compressor alone, an auxiliary compressor is employed with a double acting main compressor so that the piston of the latter has only to overcome inherent resistance.

The right is reserved, however, to employ in certain cases a single compressor wherein the piston is made to move very slowly when it has generated the volume V_2-V_1 it will generate the volume V_3-V_2 or after having reduced the volume V_3 to the volume V_4 it will reduce again the latter to the volume V_1.

The preceding arrangements permit the impelling to be very economically effected. But the system must be so constructed as to reduce to a minimum the frictional resistances of the compressor D.

The displacement of the piston is effected by a cam L (Fig. 7) upon which roll two diametrically opposite rollers l^1 and l^2. The contour of this cam is obtained in the following manner.

Let Λ_0 be the stroke of the piston. Two concentric arcs of circles having a common centre O symmetrical with respect to a centre line O x and of radii R and $R+\Lambda_0$ are drawn, each subtending an angle equal to

$$\pi\left(1-\frac{1}{n}\right).$$

These two arcs are joined at their extremities by means of curves having the equation in polar co-ordinates

$$\rho=R+\tfrac{1}{2}\Lambda_0\,(1-\cos nw).$$

The centres of the two rollers l^1 and l^2 should follow the circuit constituted by the two circular arcs and their connecting curves.

Let r be the radius of these rollers: if from numerous points of these circuits taken as centers, arcs of radius r are described, their boundary will be the profile to be given to the cam.

The distance of the axes of the two rollers being constant and equal to $2R+\Lambda_0$ their bearings may be carried on a single frame M M (Figs. 4 and 5) fixed to the piston rod.

This frame will be rigidly connected to rods N N (Figs. 4 and 5) which are engaged in fixed slides P P, by which they will be guided.

The friction of the piston rings and the extent of leaking by are proportional to the diameter of the piston while the volume which it displaces is proportional to its square.

It will therefore be advisable for generating a given volume to give a very large diameter and a small stroke to the piston. This is what has been done. This presents no inconvenience in practice, the undesirable space being relatively large and the cam being so much the easier to operate as the stroke of the piston is smaller.

But with this arrangement considerable effort will be exerted on the piston by the differences of pressure. There is no need for it to result in an increase in the inherent resistances of the machine.

Reverting to a diagram which consists of two adiabatic lines symmetrically disposed with respect to the ordinate passing through their centre, it is proved that the difference of their ordinates is proportional at each instant to the difference of pressure supported by the piston.

If a curve is drawn taking for y the differences of these ordinates and for x the distances of these ordinates to the centre of the curves of the above diagram, a curve is obtained (Fig. 8) which may be compared very approximately with a line passing through the origin of the co-ordinates. The circumstances are such as if the pistons were urged by a spring towards their middle positions.

Under these conditions, supposing the piston first to be maintained at one end of its stroke and then released, the difference of pressure which it supports will first impart kinetic energy to it and subsequently stop it. If it did not have to overcome friction it would go of itself to the other end of its stroke, during the time of which the path which it will have traversed will be a sinusoidal function of time of the form

$$\tfrac{1}{2}\Lambda_0\left(1-\cos\frac{\pi t}{\theta}\right),$$

of which θ is the time which it takes to go from one end to the other of its stroke.

In acting either upon the speed of rotation N (in revolutions per second) of the compressor D or upon the mass of the piston, the factor n, or finally on the pressure P_1 of the air, the condition

$$2\pi N=\frac{1}{\theta}$$

is produced.

Under these conditions, the cam will only make the piston follow in its course, imparting to it only the work necessary for overcoming the friction of the rings and the stuffing box, without the difference of pressure supported by the piston intervening.

But it will be the rollers l^1 and l^2 which will maintain the piston motionless and they will then have to support the force developed on the piston. They will act strongly as a brake upon the cam.

In order to avoid this defect the piston is caused to rest against a fixed stop during practically the whole time at which it is at rest, this being as follows:

The several valves are operated in properly timed relation by means of a disk I. The required oscillation movement will be communicated to the disc I by means of two cams, such as that represented by W^1 in Fig. 11, displaced 180° with respect to one another and disposed like the cams L upon the shafts of the motor but on the other sides of the bearings X_1 and X_2; the rollers V_1 and V_2 are applied to said cams and are disposed at the extremities of levers pivoted about the fixed points Y_1 and Y_2. The other extremities of these levers act upon the disc I through the intermediary of rods Z Z furnished with ball joints. The roller pressed by one cam operates the system and maintains at the same time the other roller in contact with its cam.

The cams in rotating impart an oscillatory movement to the disc I. They will be timed with respect to the cam L so that this movement will have the desired phase.

Let $\frac{2}{K}\pi$ be the angle through which the disc I (Fig. 3) turns to right or left for actuating the valves.

Upon the piston rod is arranged a dog Q having $\frac{K}{2}$ teeth Figs. 4, 5, 9 and 10. This disc I carries an interiorly toothed hollow dog S into which the dog Q can be received as shown in Figs. 4, 5, 9 and 10. The two dogs Q and S are thus disposed with their teeth in mesh when the disc I is in its intermediate position and all the valves are shut. The rod may then move freely and the piston can move from one end of its stroke to the other.

When the piston reaches one end of its stroke the dog Q moves beyond the dog S to one side or the other by a very small amount (Figs. 4 and 5).

The disc I then turns in one direction or the other by $\frac{1}{K}$ of a revolution. The dog S thus rotates through part of a tooth space and if the dog Q is released its teeth will come into engagement with the other teeth which it cannot pass, (Fig. 10).

The cam L has only to hold the piston still during the operation of the valves, namely during a time $\frac{2}{n'}$. As shown in Fig. 4 the cam is recessed from t to u. After the disc I has opened the valves, the cam will recede from that of the two rollers l^1 and l^2 which will be pressed against it and the dog Q will come to rest on the dog S. The moment before the closure of the valve the cam will lift said roller and liberate the disc I.

The machine thus constituted will have a very good performance because the work which it has to produce, that is the work successively imparted to and taken from the air, is much smaller than in the old machine using air and also because a special machine is available for its production wherein all the inherent resistances are reduced to a minimum.

At the same time it is much lighter and less cumbersome than the old machines, its pistons displace only the volume $V_3—V_1$ per kg. of air describing the cycle instead of having to displace the volume V_2+V_3.

The air cooler may be omitted by closing the cycle of the machine through the atmosphere, as may sometimes be advantageous. This arrangement will be particularly appropriate for lowering a temperature above zero by thermometer as there will be no fear of the formation of snow in the machine and no need to take special precautions for removing it.

In general, it will be preferable to supply always the same quantity of air forming the cycle through a refrigerator. Thus not only is one no longer concerned with snow but a higher pressure can be given to the air and, other conditions being equal, the power of the machine will be proportional to the pressure P_1. Furthermore, the power of the heat exchangers (cooler and refrigerator) will also increase with the pressure P_1. Very light machines which are also not very cumbersome in respect to their power are thus available.

As will be well understood, the machine lends itself to the same applications as all refrigeration machines using ammonia, sulphurous acid, etc.

It will be understood that all the arrangements which have been described by way of example in no way limit the invention and that modifications may be introduced without departing from the scope of the invention.

What I claim is:—

1. A method of refrigerating which consists in compressing a body of gas of relatively high temperature received from a refrigerator to effect a still further rise in the temperature thereof, circulating the gas under pressure through a cooling device, by causing its displacement by a second body of gas at the same pressure and at a lower temperature received from said cooling device, expanding the second body of gas to cause a further lowering in the temperature thereof, delivering said second body of gas to the refrigerator by causing its displacement by a third body of gas received from the refrigerator, compressing the third body of gas, circulating the same through the cooling device by causing its displacement by means of the first mentioned body of gas received from said cooling device, expanding said first mentioned body of gas to cause a further lowering of the temperature thereof, and circulating said first mentioned body of gas relatively cold through said refrigerator by causing its displacement by said second body of gas received from said refrigerator.

2. A method of refrigerating which consists in compressing a volume of gas, cooling the gas while under compression, expanding the cooled gas so as to cause a further decrease in the temperature thereof, delivering said expanded gas to a refrigerator, removing the gas from the refrigerator and repeating said cycle of operations, deducting gas from the evaporator and adding it to the cooled compressed gas to prevent gas from accumulating in said refrigerator.

3. A refrigerating machine comprising a refrigerator, a cooling device associated therewith, a compressor and expander, associated with said refrigerator and said cooling device, means for establishing communication between said refrigerator and said compressor and expander, means for establishing communication between said compressor and expander and said cooling device, impelling means for causing the circulation of a cooling medium through said elements, valve mechanism disposed in each of said communicating means, and means for actuating said valve mechanism in timed re-

lation with respect to the operation of said compressor and expander to permit said impelling means to first deliver gas at a relatively low temperature to said compressor and expander to be compressed thereby, then to be circulated through said cooler, then to be expanded by said compressor and expander and finally to be delivered to said refrigerator.

4. A refrigerating machine comprising a refrigerator, a cooling device associated therewith, a compressor and expander, associated with said refrigerator and said cooling device, means for establishing communication between said refrigerator and said compressor and expander, means for establishing communication between said compressor and expander and said cooling device, impelling means for causing the circulation of a cooling medium through said elements, valve mechanism disposed in each of said communicating means, means for actuating said valve mechanisms in timed relation with respect to the operation of said compressor and expander to permit said impelling means to first deliver gas at a relatively low temperature to said compressor and expander, to be compressed thereby, then to be circulated through said cooler, then to be expanded by said compressor and expander and finally to be delivered to said refrigerator, and means for deducting a predetermined amount of gas from said refrigerator and delivering it to said cooling device.

5. A refrigerating machine comprising a refrigerator, a cooling device associated therewith, a compressor and expander, associated with said refrigerator and said cooling device, means for establishing communication between said refrigerator and said compressor and expander, means for establishing communication between said compressor and expander and said cooling device, impelling means for causing the circulation of a cooling medium through said elements, valve mechanism disposed in each of said communicating means, means for actuating said valve mechanisms in timed relation with respect to the operation of said compressor and expander to permit said impelling means to first deliver gas at a relatively low temperature to said compressor and expander to be compressed thereby, then to be circulated through said cooler, then to be expanded by said compressor and expander and finally to be delivered to said refrigerator, and an auxiliary compressor for supplementing the mass of gas in said cooling device by gas taken from said refrigerator.

6. A process for accomplishing refrigeration by means of a gas such as air, which consists in compressing the air, in cooling it, in effecting the expansion of the air and thereby cooling it, in impelling this expanded cold air, which is intended for the production of cold, by air at the same pressure which has given up its cold, in compressing to the initial pressure the said air which has given up its cold and has just been exchanged, and then, after compression, in impelling the said air by air at the same pressure which has given up its heat, in compressing the excess of air which has given up its cold in order to bring it back to the initial pressure, and in recommencing the cycle of operations.

7. In an apparatus for accomplishing refrigeration by means of air, an air cooler, a refrigerator, a main compressor having a piston adapted to reciprocate therein so as to compress air on one side thereof to the pressure prevailing in the air cooler and to simultaneously expand the air on the other side thereof to the pressure prevailing in the refrigerator, communicating means between said air cooler and said compressor on each side of said piston, communicating means between said refrigerator and said compressor on each side of said piston, means for opening and closing said communicating means, means for impelling compressed air from said compressor by air at the same pressure from said air cooler and means for simultaneously impelling expanded air from said compressor by air at the same pressure from said refrigerator.

8. In an apparatus for accomplishing refrigeration by means of air, an air cooler, a refrigerator, a main compressor having a piston adapted to reciprocate therein so as to compress air on one side thereof to the pressure prevailing in the air cooler and to simultaneously expand air on the other side thereof to the pressure prevailing in the refrigerator, communicating means between said air cooler and said compressor on each side of said piston, communicating means between said refrigerator and said compressor on each side of said piston, means for opening and closing said communicating means, means for impelling compressed air from said compressor by air at the same pressure from said cooler, means for simultaneously impelling expanded air from said compressor by air at the same pressure from said refrigerator and an auxiliary compressor adapted to withdraw excess air from said refrigerator and transfer it to said cooler.

9. In an apparatus for accomplishing refrigeration by means of air, an air cooler, a refrigerator, a main compressor having a piston adapted to reciprocate therein so as to compress air on one side thereof to the pressure prevailing in the air cooler and to simultaneously expand the air on the other side thereof to the pressure prevailing in the refrigerator, communicating means be-

tween said air cooler and said compressor on each side of said piston, communicating means between said refrigerator and said compressor on each side of said piston, means for opening and closing said communicating means, a fan for impelling compressed air from said compressor by air at the same pressure from said air cooler, a second fan for simultaneously impelling expanded air from said compressor by air at the same pressure from said refrigerator and an auxiliary compressor adapted to withdraw excess air from said refrigerator and transfer it to said cooler.

10. In an apparatus for accomplishing refrigeration by means of air, an air cooler, a refrigerator, a main compressor having a rectangular air space at each side thereof, a piston in said compressor adapted to reciprocate so as to compress air in one of said spaces to the pressure prevailing in the air cooler and to simultaneously expand air in the other of said spaces to the pressure prevailing in the refrigerator, communicating means between said air cooler and each of said spaces including valves disposed upon opposite sides of said spaces, communicating means between said refrigerator and each of said spaces including valves disposed upon opposite sides of said spaces and means for operating said valves in timed relation to the reciprocations of said piston.

11. In an apparatus for accomplishing refrigeration by means of air, a main compressor having a piston adapted to reciprocate therein so as to compress air on one side thereof and to simultaneously expand the air on the other side thereof, a driving shaft having a cam for reciprocating said piston so formed as to permit a natural movement of said piston under the impulse of pressure exerted by the compressed air on one side thereof and positive means for causing said piston to dwell at each end of its reciprocation.

12. In an apparatus for accomplishing refrigeration by means of air, a main compressor having a piston adapted to reciprocate therein so as to compress air on one side thereof and to simultaneously expand air on the other side thereof, a driving shaft having a cam for reciprocating said piston so formed as to permit a natural movement of said piston under the impulse of pressure exerted by the compressed air on one side thereof, a toothed dog connected to said piston so as to reciprocate therewith, an annular toothed dog surrounding said first dog and means for relatively rotating said dogs at each end of the reciprocation of said piston so as to prevent relative movement between said dogs and cause said piston to dwell at each end of its reciprocation.

13. In an apparatus for accomplishing refrigeration by means of air, a main compressor having a piston adapted to reciprocate therein so as to compress air on one side thereof and to simultaneously expand air on the other side thereof, a driving shaft having a cam for reciprocating said piston so formed as to permit a natural movement of said piston under the impulse of pressure exerted by the compressed air on one side thereof, a toothed dog connected to said piston so as to reciprocate therewith, an annular toothed dog surrounding said first dog and means for rotating said annular dog at each end of the reciprocation of said piston so as to prevent relative movement between said dogs and cause said piston to dwell at each end of its reciprocation.

In testimony whereof I have signed this specification.

CHARLES LÉONARD ARMAND MAURICE LEBLANC.