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R. ESNAULT-PELTERIE
PROCESSES FOR THE PRODUCTION OF HEAT OR COLD BY MEANS OF A THERMAL PUMP WITH PISTONS AND TO THERMAL PUMPS FOR THE WORKING OF THESE PROCESSES
Filed Feb. 13, 1942

Serial No.
430,814
2 Sheets-Sheet 1

Fig.1.

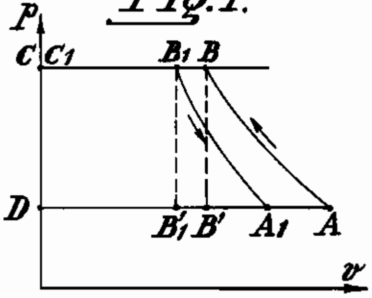


Fig.2.

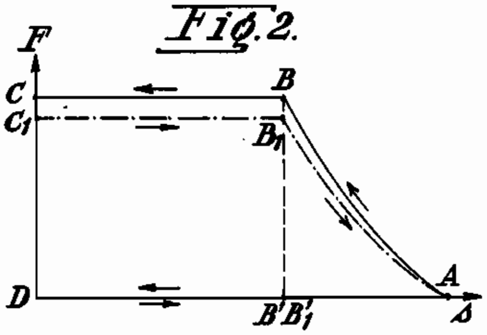


Fig.3.

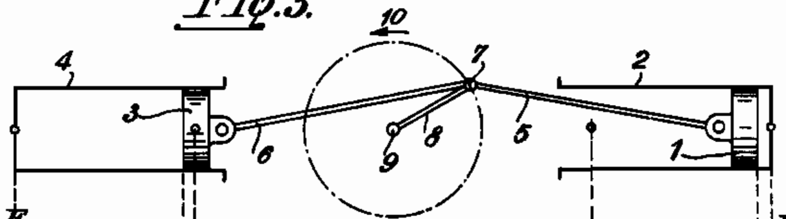


Fig.3a.

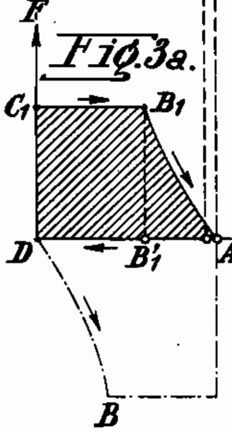


Fig.3b.

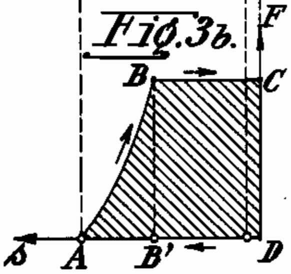
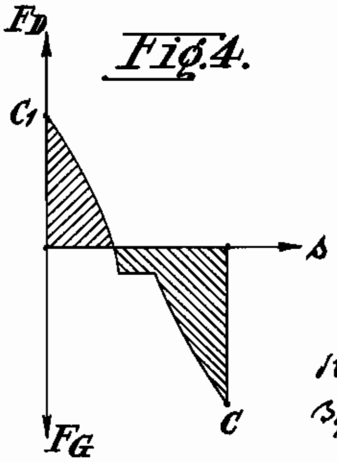


Fig.4.



Inventor:
R. Esnault-Pelterie
By G. F. Wenderoth
Atty

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Fig. 5.

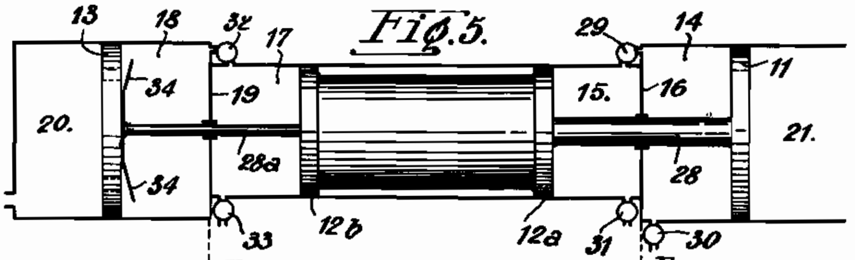


Fig. 5a.

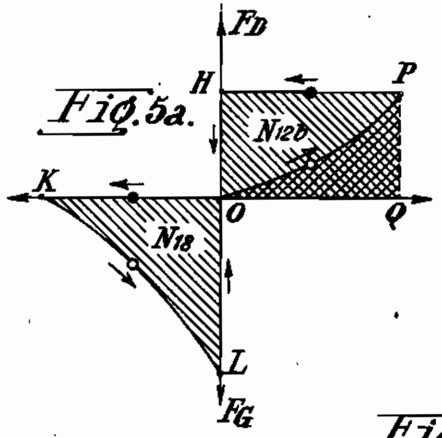


Fig. 5b.

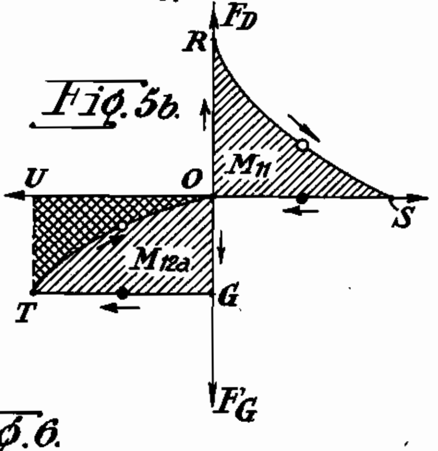


Fig. 6.

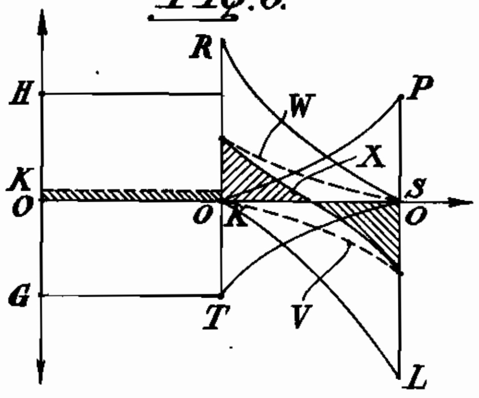
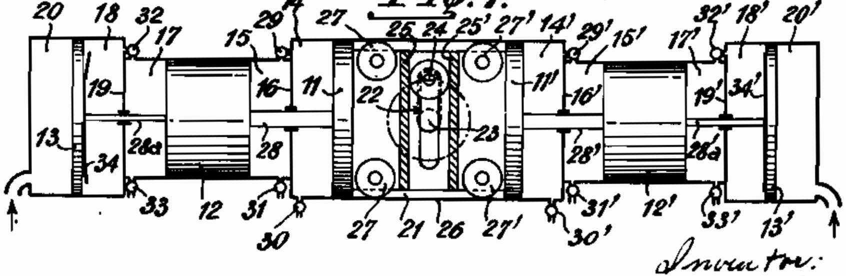


Fig. 7.



Inventor:
R. Esnault-Pelterie
By C. F. Wenderoth Atty

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PROCESSES FOR THE PRODUCTION OF HEAT OR COLD BY MEANS OF A THERMAL PUMP WITH PISTONS AND TO THERMAL PUMPS FOR THE WORKING OF THESE PROCESSES

Robert Esnault-Pelterie, Geneva, Switzerland; vested in the Alien Property Custodian

Application filed February 13, 1942

If the *p*, *v* diagram (Figure 1) of a thermal pump for non-condensing fluid is considered, it will be seen that the major part of the work brought into play is neither the one of compression represented by the mixtilinear triangle ABB′, nor the one of expansion $B_1A_1B_1'$, but the one of expulsion at high pressure $DC_1B_1B_1'$ (it is assumed on the diagram that pressure which is to be considered as ambient is the low pressure of the cylinder under consideration).

It is possible to establish a diagram in a different way by plotting as ordinates the total forces F developed on the pistons and as abscissae the corresponding strokes *s* of the said pistons; on Figure 2, which represents such a diagram, it has been assumed that although the stroke is the same for both the compression and the driving pistons, the cross-section of the latter is inferior to that of the former by the amount (7 to 15% according to the case) necessary in order to consider the cooling which takes place between the end of compression and the beginning of the corresponding expansion, as well as the correlative heating which takes place between the end of the expansion and the beginning of the compression. The same reference letters have been used in this diagram as in the first one for denoting the corresponding points (on the first diagram C and C_1 are in coincidence, whereas on the second it is B′ and B_1' which are in coincidence) and it will be seen that the same result is obtained.

In pumps of the usual type the compression work with transfusion ABCD is entirely supplied by the machine, and the expansion work with transfusion DC_1B_1A is entirely received; the friction losses in the guiding members of the pistons as well as the lateral friction of the latter being proportional to the sum of the absolute values of this work, whereas the work to be supplied per cycle is equal only to their difference.

The more one attempts to obtain a higher thermal efficiency by reducing the amount of cooling or heating mentioned above (by actually reducing the temperature difference), the more the above inconvenience is exaggerated. This fact may be considered to be the fundamental cause of the difficulty encountered with in the design of thermal pumps for non-condensing fluids, and the mathematical analysis shows that a useful thermal efficiency may be obtained from such a machine only under the condition that the mechanical efficiency is kept extremely high.

The present invention aims to eliminate the above inconvenience. It comprises an improved process for the production of heat or cold by means of a thermal pump which is characterized in that the compression and the expansion are localized on one stroke and the corresponding transfusion work in the inverse stroke. The present invention also comprises a thermal pump for the working of the said process, characterized in that the compression and the expansion operations of the evolutive fluids are localized on one stroke, whereas the corresponding transfusion work is localized on the inverse stroke.

The accompanying drawings show, by way of example, one embodiment of the thermal pump which the invention comprises, illustrating one way of working of the process.

Figures 1 and 2 are the two diagrams which have been discussed in the introduction.

Figure 3 schematically illustrates how things happen in the case of a thermal pump of known type, this in order to clearly demonstrate the progress achieved by the present invention.

Figures 3*a* and 3*b* are two diagrams relating to the operation of the thermal pump as per Figure 3.

Figure 4 is a diagram referring also to the case of Figure 3.

Figure 5 schematically illustrates one portion of the constructional form of the thermal pump according to the invention, which will be described below.

Figures 5*a* and 5*b* are two diagrams referring to the thermal pump as per Figure 5.

Figure 6 is another diagram referring to Figure 5, and

Figure 7 schematically illustrates the whole arrangement of compression and driving cylinders and pistons included in this embodiment.

In Figure 3, a driving piston **1** is illustrated to move in a cylinder **2** and a compression piston **3** to move in a cylinder **4**, the latter being arranged in alignment with the cylinder **2**. Both of the pistons under consideration are each connected by means of a rod **5** and **6** respectively to a pin **7** of a crank-arm **8** carried by a shaft **9** which is driven in the direction indicated by the arrow **10** by a motor, which is not shown in the drawing. The F, *s* diagram corresponding to the driving piston **3** is shown on Figure 3*a*, whereas Figure 3*b* shows the F, *s* diagram corresponding to the compression piston **1**. The same reference letters as in Figure 2 have been used in both these figures for the corresponding points.

In order to obtain a representation of the forces acting on the articulated system of the driving mechanism, particularly in point 7, it is suitable to plot the positive diagram as per Figure 3_b against the negative diagram as per Figure 3_a, as this has been indicated in dash-dotted lines, and to establish for every value of abscissae the algebraic sum of the ordinates. In fact, the ordinates of the diagram of Figure 3_a represent forces acting on the piston 3 in the right hand side direction, whereas the ordinates of the diagram of Figure 3_b represent forces acting on the piston 1 in the left hand side direction. The diagram of Figure 4 represents the resultant forces acting on the articulated system, and this in function of the stroke of the pistons. The positive ordinates indicated by F_D represent forces acting in the right hand side direction, and the negative ordinates indicated by F_G represent forces acting in the left hand side direction. It will be seen in Figure 4 that the positive and negative forces acting on the pistons counterbalance each other during a short period of the stroke only.

In the example of the constructional form of the thermal pump according to the invention, which is going to be described below, a pressure ratio or two has been assumed, which represents an average value and which corresponds to a volumetric ratio of about 0.6. It is understood, that these values have been chosen by way of examples and do in no way limit the scope of the invention.

Figure 7 shows the whole of two trains of three pistons each arranged symmetrically with respect to a central driving crankshaft.

The following description mentions the left side of the figure only, as the functioning of the right side is the same and homologous parts bear corresponding reference numbers. It will also be possible to follow the description of the left train of the constructional form of the pump as per Figure 7 by using the Figure 5. This train embodies the pistons 11, 12_a, 12_b and 13 mounted on the same rod. The piston 12_a, 12_b is, in fact, the equivalent of two pistons rendered integral, as both of its faces are active, as will be seen below. The pistons 11 and 12_a form the boundaries of two spaces 14, 15 separated by a fixed partition 16, whereas the pistons 12_b and 13 form the boundaries of two other spaces 17, 18 separated by a fixed partition 19.

A space 20, located at the outside extremity of the machine, is in communication with the low pressure pipe of the thermal pump; in the centre a chamber 21, forming a case, which may advantageously be connected with the low pressure pipe, contains the crank 22 (Figure 7) carried and driven by the shaft 23 and carrying on its pin 24 a ball, roller or needle bearing which rolls in a transversal slot limited by two surfaces 25, 25′ integral with the crosshead formed by the two homologous pistons 11, 11′ and guided inside the cylindrical case 26 (which may also be rectangular) by the bearings 27, 27′.

As the volumetric ratio in the present example has been chosen to be 0.6, the faces of the pistons 12_a, 12_b possess each an active surface amounting to 0.6 of that of the opposed pistons 11 and 13 respectively. As the active section of piston 11 (which, as will be seen below, is a driving piston), has to be inferior to that of piston 13 (which will be seen below, is a compression piston), the difference in surface necessary to take into account the temperature difference of the fluid in contact with the two pistons is obtained by giving to the portion 28 of the rod connecting the pistons 12_a and 11 a greater diameter than to the portion 28_a of this rod connecting the pistons 12_b and 13. If for constructional reasons the two pistons 11 and 13 should be of the same diameter, the ratios would no more be respected, but this could be remedied by suitably altering the dead spaces at the end of the stroke.

The portion 28_a of the rod connecting the pistons 12_b and 13, which is never stressed otherwise than in traction, may be of a smaller diameter without risks of buckling failure. The functioning of the portion of the thermal pump illustrated in Figure 5 is the following:

The pistons being in the middle of their stroke as shown in the drawing and the crank 22 rotating anticlockwise, the pistons shown in Figure 5 are moving towards the left. At this moment, a valve 29 permitting to establish the communication between the driving cylinders 14 and 15, is shut and interrupts this communication. The driving piston 11 which is moving in the space 14, expels at low pressure through a valve 30, whereas the driving cylinder 15 is charged with high pressure gas through a valve 31. Meanwhile a connection valve 32, provided for establishing communication between the compression cylinders 17 and 18, is shut and the compression cylinder 17 is being emptied into the high pressure pipe of the thermal pump through a valve 33, whereas the compression cylinder 18 is being filled with low-pressure gas through automatic valves 34 carried by the piston 13. When the train of pistons 11, 12_a, 12_b and 13 reaches the end of the stroke and moves back towards the right, the valves 30, 31 and 33 are shut and the flap-valve 34 shuts automatically. During this stroke, carried out in the inverse direction to the preceding, the valves 29 and 32 are open and establish a connection between the driving cylinders 14 and 15 and the compression cylinders 17 and 18 respectively; thus the gas is compressed at the left (Figure 5) in the whole space formed by the cylinders 17 and 18, whereas it simultaneously expands in the whole space formed by the two cylinders 14 and 15.

In order to properly understand the functioning of the apparatus, it is necessary to refer to the diagrams in Figures 5_a and 5_b. In these diagrams the positive ordinates F_D represent forces acting on the pistons in the right hand side direction and the negative ordinates F_G represent forces acting on the pistons in the left hand side direction, whereas the abscissae represent the piston strokes. The points of the diagrams corresponding to the position of the active surface of each piston situated exactly above these points are shown by small black circles under the assumption that the pistons are moving towards the left. The points on the same diagrams corresponding to the same position of the active surface of each piston, under the assumption that the pistons are moving towards the right, are shown by small white circles. The arrangement adopted in the diagram of Figures 5_a and 5_b results in that they represent work diagrams described in the usual direction (clockwise for a positive work and anticlockwise for a negative work). The letters M indicate a driving cycle, i. e. positive work, and the letters N indicate a compression cycle, i. e. negative work. The letters M and N are indexed with the corresponding piston numbers.

In examining these diagrams, it will be seen that when the pistons are moving towards the left, the cylinder 15, which is being charged at high pressure, develops a force OG acting towards the left on the piston 12_a and producing positive work shown by a shaded rectangle. Simultaneously the cylinder 17, which is being discharged at high pressure develops a force OH acting towards the left on the piston 12_b and producing negative work shown by a rectangular shaded surface.

The active surface of the piston 12_a being smaller than the one of piston 12_b these two forces and their respective work are not canceling each other; their algebraic sum is represented by OK on Figure 6. The small negative work done by this force equal to the arithmetic difference of the amounts of work corresponding to the transfusion work (large rectangle in Figures 1 and 2) is represented by the small shaded rectangle in Figure 6. Thus, it will be seen that the force transmitted to the driving pistons during their motion towards the left is far from being the sum of the forces acting on the pistons during the transfusion, and is equal to their difference; the correlative losses in the mechanism will therefore be proportional to this difference and not to this sum.

As it was stated that the difference of the cross-sections in the present case amounts to some 7 to 15%, it will be seen that this arrangement reduces the stresses corresponding to the transfusion, which represent the major part of the work brought into play, by some 95% as compared with a machine of known type. Without pretending that the losses would actually be reduced to such an amount, it may be assumed that the reduction will be up to about 90%, which is already a satisfactory achievement, this work representing as stated the major part of the total work brought into play (generally almost ¾ of the total work).

In the example shown, it has been assumed that during the motion towards the left of the pistons shown in Figure 5, the low pressure exists on both sides of the pistons 11 and 13 and that, therefore, the resulting force exerted on them by the fluid is nil, what explains that the point on the diagrams Figures 5_a and 5_b corresponding to the position of these pistons is on the axis of abscissae. When the train of pistons according to Figure 5 returns towards the right, the gas contained in both cylinders 17 and 18, which are in communication, is being compressed while exerting on the piston 13 a force directed towards the left and which is gradually increasing as per curve KL, i. e. absorbing the work KLO. During the same piston stroke, the gas exerts on the piston 12_b a force directed towards the right and which is gradually increasing as per curve OP, i. e. developing a positive work OPQ. During the motion of the pistons towards the right the gas contained in the cylinders 14 and 15, which are then in communication as already seen, expands while exerting on the piston 11 a force directed towards the right and which is gradually decreasing as per curve RS, i. e. producing a positive work ORS. In expanding, the gas contained in the cylinder 16 exerts on the piston 12_a a force directed towards the left and which is gradually decreasing as per curve TO, i. e. producing negative work TOU.

In Figure 6, the curves KL and OP are shown opposite each other and the dotted line V indicates the algebraic sum of their ordinates, i. e. the algebraic sum of the forces acting on the pistons 12_b and 13 during the stroke towards the right. In Figure 6, the curves RS and TO have also been shown opposite each other, as well as the algebraic sum of their ordinates represented by the dotted curve W. Therefore, this curve W represents algebraic sum of the forces exerted by the gas on the pistons 11 and 12_a during the movement of these pistons towards the right.

Finally the curve representing the algebraic sum of the ordinates of the curves V and W is shown by X in Figure 6, i. e. the resultant of the forces exerted by the gas on the pistons 11, 12_a, 12_b and 13 during the stroke of these pistons towards the right. It will be seen that this resultant force performs a small positive work, which is represented by a shaded curvilinear triangle above the axis of abscissae, and a small negative work represented by a shaded curvilinear triangle below the axis of abscissae. In this case there is no compensation, but it will be seen on the diagram that the sum of the absolute values of such work represented by the shaded triangles (to which the losses are proportional) is small as compared with any one of the shaded surfaces shown in Figures 5_a and 5_b, so that a very important reduction of the losses is obtained during the stroke towards the right.

The functioning of the parts shown on the right hand side of the Figure 7 will now be easily understood; it is similar to that of the parts on the left hand side, apart a question of symmetry.

Although the apparatus will work with one side in action only, a better balance (from the point of view of forces) will be obtained if it is double-sided, such as schematically shown in Figure 7.

If it is desired to balance the inertia, two groups of pumps may be arranged in tandem and provided with inverse movements, or side by side, near enough, so as the moments developed will be small.

Still in a more simple way the two halves of the mechanism shown in Figure 7 may be actuated in opposite directions by driving them separately by two crank-arms set at 180°; the two possible solutions are then:

(*a*) each of the two groups are arranged as in Figure 7, only the simultaneity of the phases is changed as it will easily be understood. The four transfusions then take place simultaneously with the production of a small total moment, but the two phases compression-expansion are also simultaneous with superposition of their negative and positive work, which increases the maximum efforts acting on the machine;

(*b*) one of the two groups is inverted; in this case a proper equilibrium of forces due to pressures as well as due to inertia is obtained.

It would also be possible in an alternative to provide that the two pistons 12_a and 12_b, instead of being integral, are connected both to a crank pin, each through a connecting rod. In this case, the apparatus could possess two compression and two driving pistons only.

If it is desirable to alter the compression ratio, it is possible to simultaneously alter in the inverse directions the dead compression and expansion spaces by shifting longitudinally each of the cylinder groups in the direction required in order to produce the same respective variations in each group; this may be accomplished, for example, by means of a screw, rack or link mechanism, preferably irreversible. As the pressure ratio would then be different from the one for which the apparatus has been designed, it would be necessary to use under- and overpressure safety valves, of the type described in Swiss Patent No. 61409, and this at least for the driving cylinders. Such valves should be fitted to the compression cylinders if they possess mechanically-operated valves. On the driving cylinders, it is advantageous to locate such safety valves on the partition 16 and on the piston 11, these valves being identical with the automatic valves being in the homologous position on the compression side. For example, the fingered valve described in the Swiss Patent No. 61,409 may be used.

The part 32, which has been indicated to be a valve, may be replaced by an automatic annular flap-valve fitted to the partition 19; the same refers to 33. The flap-valves thus substituted may be of any type, the one in partition 19 may, for example, be of the fingered shape as described in the patent mentioned above, the flap-valve 34 being, for example, constituted by a narrow and long swinging blade covering a slot extended at right angles to the plane of Figure 3.

In order to economize power, the mechanically-operated valves will be preferably of the type described in Swiss Patent No. 61409 driven by a cam mechanism having two races with double rollers and a recovery of kinetic energy.

ROBERT ESNAULT-PELTERIE.