June 19, 1923. 1,459,270

R. VUILLEUMIER

METHOD OF AND APPARATUS FOR HEAT DIFFERENTIATION

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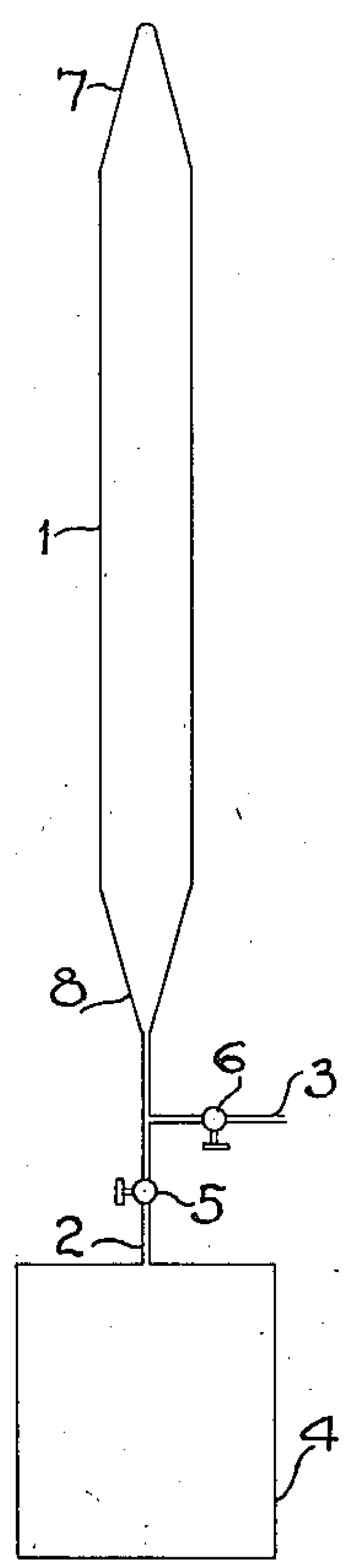
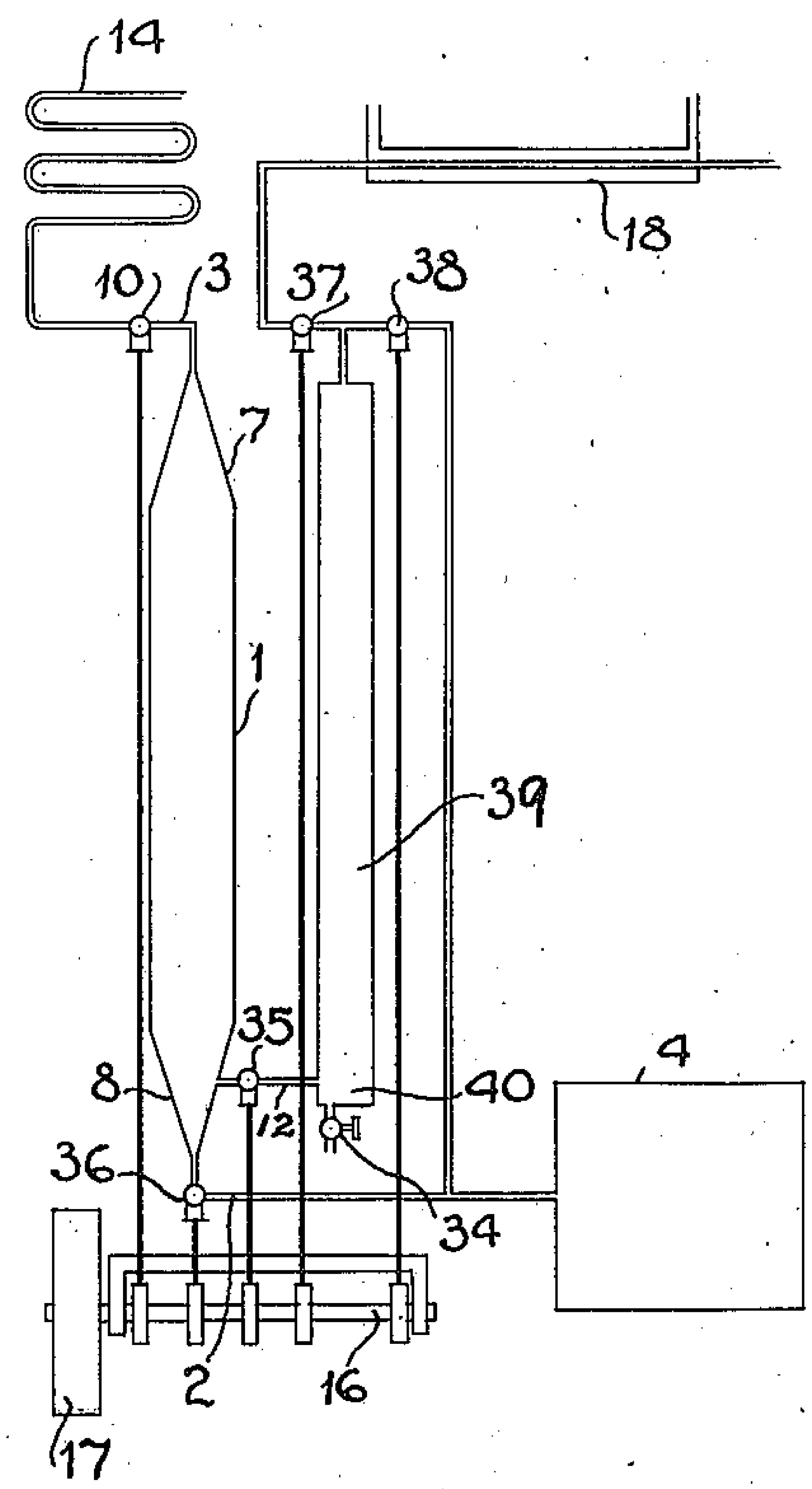
Fig: 1



Event	Valves open
Inlet	5
Outlet	6

Fig: 2



Event	Valves open
1st Inlet	36
2nd Inlet	38,35
Hot Outlet	10
Cold Outlet	35,37

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By his Attorneys

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UNITED STATES PATENT OFFICE.

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METHOD OF AND APPARATUS FOR HEAT DIFFERENTIATION.

Original application filed May 14, 1914, Serial No. 838,475. Divided and this application filed September 30, 1919. Serial No. 327,413.

To all whom it may concern:

Be it known that I, RUDOLPH VUILLEUMIER, a citizen of the United States, and a resident of New Rochelle, in the county of Westchester and State of New York, have invented an Improvement in Methods of and Apparatus for Heat Differentiation, of which the following is a specification.

This invention relates to thermodynamic apparatus, and with regard to certain more specific features, to apparatus adapted for mechanical cooling or heating or for effecting simultaneously a cooling and a heating operation. This application is a division of my application, Serial No. 838,475, filed May 14, 1914, which has matured into Patent No. 1,321,343.

One of the objects of the invention is to provide efficient and practical refrigerating means which shall be economical in consumption of power and readily adaptable to the liquefaction of air and other gases. Another object is to provide inexpensive and reliable refrigerating apparatus in which the energy abstracted in cooling the heated portions is made useful, as for heating purposes. Another object is to provide a durable and simple heating device of high thermal efficiency. Another object is to provide commercially practical apparatus in which the heat-content of the working fluid is caused to be unequally distributed and the portions of respectively increased and decreased heat-content separated before the heat-content has resumed its former condition of distribution throughout the fluid. Another object is to provide refrigerating apparatus of simple construction in which losses of the magnitude encountered in apparatus hitherto devised are largely eliminated. Other objects will be in part obvious and in part pointed out hereinafter.

In the accompanying drawings, wherein are shown diagrammatically one or more of various possible embodiments of the several features of the invention, together with such explanatory diagrams as will facilitate an understanding of the same,

Figure 1 illustrates, by way of preliminary explanation, an apparatus in which certain of the events in the cycle of operations of the apparatus may be effected.

Figure 2 illustrates in diagrammatic form a differentiator, a self-intensifying regenerator associated therewith, and certain elements for effecting the desired sequence of events.

Similar reference characters refer to similar parts throughout both views of the drawings.

As conducive to a clearer understanding of the several features of the invention hereinafter described, it may be stated that there has long been an insistent demand for reliable and inexpensive refrigerating apparatus for the attainment of low temperatures, such as that of liquid air, as well as for work requiring higher but still sub-normal temperatures. In ice machines for example, the energy efficiency is remarkably low compared to many other classes of apparatus, although there is at the present time no particular difficulty in operating with the comparatively small temperature range required for such work. But as lower temperatures are demanded, the energy efficiency of present-day apparatus is far less even than in ice-making machines and the apparatus is more complicated, more expensive and less available for work outside a laboratory. For the still lower temperatures required in the liquefaction of gases such as air, oxygen, nitrogen and hydrogen, the low efficiency and the complication of the apparatus now in the market has made impracticable any extensive use or inexpensive manufacture of the products of such machines. In the present invention, as exemplified in the apparatus herein described, there is shown a type of machine differing from those heretofore available not only in its simplicity and high efficiency, but in its mode of operation.

According to the present embodiment of this invention, apparatus is provided for utilizing periodically a quantity of fluid, altering the conditions in this fluid in such a way as to increase the heat-content of portions and decrease the heat-content of other portions, and then before an appreciable amount of this heat differentiation has been neutralized, as by convection and radiation between the heated and cooled portions, the two portions are separated from each other, the heated portion giving up its heat later in one part of the apparatus while in another part the cooled portion of the fluid is available for use in whatever way it may be needed. The apparatus therefore comprises what may be termed a "heat differentiator" to distinguish it from the various types of apparatus operating on other thermodynamic cycles. The prior art is replete with embodiments of such cycles involving usually the conversion of heat energy into work, or vice versa, with the inherent loss of power and complication of apparatus attendant upon such conversion. In apparatus made according to the present invention, the working fluid itself is separated into a heated part and a cooled part, and the two parts put to whatever use may be required of them. While much, if not all of the apparatus herein illustrated or described, may be operated with any suitable fluid, the working fluid will be in general a gas.

Referring now more particularly to the accompanying drawings, there is illustrated diagrammatically in Figure 1 an apparatus exemplifying by way of introduction certain of the principles of the present invention. In this figure there is illustrated at 1 a chamber or cylinder, preferably of fixed dimension, provided with an inlet pipe 2 and an outlet pipe 3. The inlet pipe 2 leads from a source 4 of gas which is maintained at constant pressure by means not shown. The admission of fluid from the source 4 to the chamber 1 may be regulated by opening and closing the inlet valve 5 in the inlet pipe 2. Gas that is in the chamber 1 may be discharged into the atmosphere through the outlet pipe 3, under the control of a suitable outlet valve 6. Assume now merely for purposes of illustration that the value of the pressure maintained constant in the source 4 is ten atmospheres, that the inlet and outlet valves 5, 6, are both closed, with the fluid in the chamber at atmospheric pressure, and all parts of the apparatus as well as the supply gas and chamber gas at a room temperature of 60° F. If now the inlet valve 5 be opened, the gas from the source 4 will pass through the inlet pipe 2 into the chamber 1 until the chamber pressure has reached ten atmospheres. In the act of entrance, however, the gas initially contained in the chamber at atmospheric pressure and room temperature will be forced upwardly (Figure 1) toward the end 7 of the chamber, farthest from the inlet end 8 and will at the same time be compressed from one to ten atmospheres and will be correspondingly heated, though naturally after sufficient time has elapsed for the radiation and convection of heat from this gas to the walls of the chamber 1 and to the other gas in the chamber this heated portion at the far end of the chamber would be cooled to the temperature of the adjacent chamber walls and of the remaining gas in the chamber. For the moment, however, this initial chamber gas, now compressed at the far end of the chamber, will be hot. Likewise any part of the gas which enters the chamber with the exception of the very last will be compressed after it enters the chamber from the pressure prevailing in the chamber at the moment of its entrance up to the final pressure of ten atmospheres, and each portion of the air will be heated to an extent corresponding to the magnitude of this compression within the chamber. The first gas to enter the chamber through the inlet valve 5 will, of course, expand to the initial chamber pressure of one atmosphere, and then as it is pushed toward the far end of the chamber by the succeeding portions of inlet air, it will undergo an after-compression of one to ten atmospheres, which is the same as the extent of compression of the original chamber gas. The next portion of inlet gas will find the chamber pressure something above one atmosphere due to the presence in the chamber of the preceding portion of inlet gas in addition to the initial chamber gas, and the after-compression of this second portion of inlet gas will be something less than nine atmospheres; likewise, each succeeding portion of inlet gas will undergo an after-compression of progressively decreasing magnitude until, when the last portion of inlet gas to reach the chamber finds the chamber pressure up to its maximum value of ten atmospheres, no after-compression will be experienced, and the admission of gas to the chamber will cease whether the inlet valve 5 be then closed or not. It is apparent, therefore, that the filling of the chamber produces in the initial chamber gas a rise in temperature. and that each portion of the inlet gas to reach the chamber experiences a progressively decreasing rise in temperature, the temperature rise of the last portion of inlet gas being zero. Disregarding for the moment the mixing of the gas inside the chamber due to eddy currents or convection currents, and the heat-conducting action of the chamber walls, the gas temperature in the chamber at the completion of the inflow varies from room temperature at the inlet end 8 to a theoretical value at the far end 7 expressed by the equation

$$T^1 = T\left(\frac{P_1}{P}\right)^{.29}$$

in which T and T_1 are the initial and final absolute temperatures, and P and P_1 the initial and final absolute pressure. With an initial temperature of 60° F., corresponding to an absolute temperature of 519° F., and an initial and final pressure of one and ten atmospheres, respectively, at the far end 7 of the chamber, it is found that the final temperature at the far end will be approximately 1012° absolute, or 553° F., giving a range of temperature along the chamber of 553°−60°=493° F. Now if immediately upon the completion of the inflow the inlet valve 5 be closed, and the outlet valve 6 be opened, and the gas contained in the chamber under a pressure of ten atmospheres be discharged through the outlet pipe 3 into the atmosphere, it will be found that in spite of the heated condition of practically all of the chamber gas, only gas of the original temperature of 60° F. would be emitted through the outlet valve, because all parts of the chamber gas leave the chamber under the same pressure at which they entered it. For example, a gas portion that entered the chamber when the chamber pressure had attained two atmospheres experienced an after-compression of 10—2=8 atmospheres, and was pushed by the succeeding inlet gas portions approximately $\frac{8}{10}$ of the distance to the far end of the chamber, since the gas extending throughout the whole chamber at two atmospheres pressure was gradually pushed toward the far end as the pressure rose, until it could only extend $\frac{2}{10}$ of the distance from the far end 7 toward the near end 8 when the chamber pressure had attained ten atmospheres, now as the discharge progresses this selected gas portion will be permitted to travel gradually toward the inlet end (toward the bottom in Figure 1) and it will reach the inlet end when the chamber pressure has dropped to two atmospheres, since by hypothesis there are always two volumes of gas portions between the selected gas portion and the far end 7 of the chamber. From this it will be clear that each gas portion undergoes within the chamber an expansion equal to its compression therein; so that the temperature rise of each gas portion effected by the compression is balanced by an equal temperature drop of that gas portion due to expansion, neglecting losses. Since all of the gas passing through the single outlet valve 6 is at room temperature, a modification of the apparatus is necessary in order that practical use may be made of the unequal distribution of heat through the chamber-gas immediately at the close of the inlet event.

Referring now to Figure 2 for an embodiment of such a modification, and more particularly an embodiment of certain features illustrated in Figure 8 of my Patent No. 1,321,343 above mentioned, we have as before a chamber 1 provided with a constant-pressure source 4 of gas that may be admitted to the chamber through the inlet pipe 2 and inlet valve 36, but in this case the outlet pipe 3 and outlet valve 10 are placed at the end 7 of the chamber farthest removed from the inlet end 8. A second inlet valve 35 is provided, and will be described later herein. Assume for the moment that there is but the one inlet valve 36, and that after inflow therethrough has been completed and the chamber-gas is at ten atmospheres pressure, that the gas temperature is highest at the far end, as previously outlined in connection with Figure 1. If now, before equalization has taken place in the chamber-gas, the outlet valve 10 at the far or upper end 7 of the chamber be opened, and the pressure in the chamber released after the inlet valve 36 is closed, it will be found that at first gas of a much higher temperature than room temperature will leave through the outlet valve. This temperature, however, gradually diminishes until when the pressure inside the chamber is reduced to about one-half maximum, the temperature of the issuing gas has fallen to room temperature and continues to fall until the chamber pressure has been reduced to atmospheric, when a considerably lower temperature than the original temperature is reached. In other words, a differentiation or unbalancing of the heat-content of the gas portions has taken place; and from an initial supply of ten volumes of gas at room temperature, there is obtained about five volumes of warmer gas and about five volumes of cooler gas, the increase in heat-content of the warm gas equaling the decrease in heat-content of the cool gas.

When operating under the assumed pressure and initial temperature condition, the gas undergoing this temperature differentiation is changed theoretically from a uniformly distributed temperature of 60° F. to an unevenly distributed temperature, varying from minus 193° F. to plus 550° F. Furthermore, as indicated above, the quantity of heat which the gas contains after this temperature differentiation has been neither increased nor diminished, but is equal to the heat quantity which it originally contained, the heat having simply been forced to assume an uneven distribution. In other words, the operation is preferably substantially adiabatic. The above is on the assumption that the gas follows the laws of Marriotte and Guy-Lussac, and, as is well known, gases that are liquefied on a commercial scale, depart somewhat from the characteristics prescribed by these laws. When air, for instance, is the gas used, slightly lower temperatures have been observed, of the magnitude of $\frac{1}{2}$° F. per atmosphere pressure-difference between the compressed and expanded air.

It will be observed that in order to obtain a temperature differentiation the gas which issues hot issues preferably at an exit pressure higher than its inlet pressure: In other words, the compression within the chamber of such gas portions during the inflow is preferably greater than the expansion occurring within the chamber during the hot-outflow. On the other hand, the gas which issues cool issues preferably at a pressure less than the inlet pressure of the gas, in which case there is ordinarily an after-compression of smaller magnitude than the after-expansion. In other words, the temperature differentiation depends upon the pressure difference with which the respective parts enter and leave the chamber. The greater these differences, the greater will theoretically be the temperature differences.

It follows, therefore, that with the apparatus of Figure 1, where the exit pressure of each gas portion is neither greater nor less than its inlet pressure, the temperature differentiation will be practically zero, while with the modification illustrated in Figure 2, where the gas having been subjected in the chamber to the greatest compression undergoes the least expansion, and vice versa, the temperature ranges attainable are theoretically a maximum.

In order to utilize this range of temperatures, and to reduce the losses that would attend the use of the outlet 10 as the outlet for all of the chamber gas, said outlet 10 is used only as the outlet for the hot gas, while the cold exit 35 is located adjacent the opposite or inlet end 8 of the chamber 1, so that no part of the chamber walls will be alternately subjected to high and low temperatures with the attendant loss of efficiency through heat-absorption.

In this apparatus, the inlet valve 36 is opened and closed at appropriate intervals by one of the cams illustrated conventionally as mounted on the shaft 16. The hot outlet valve 10 is similarly controlled. It will be seen that with this arrangement the heat-content of the hot-outlet gas may be used for heating or other purposes by passing the hot gas through a heat-utilizing device illustrated conventionally at 14, while the cold outlet gas in the pipe 12 is passed upwardly through a regenerator 39 to serve there for the purpose of extracting heat from contiguous substances and to become itself liquefied when the apparatus has been in operation long enough.

The issuing hot gas is exhausted into the atmosphere, according to the embodiment illustrated in Figure 2, without saving whatever useful energy the gas may have in the form of pressure. A considerable economy may be effected by saving the pressure in this gas since the average pressure in the hot system is not far from half the maximum pressure prevailing in the chamber at the close of the inflow. Suitable means, not shown, may be provided for utilizing this pressure, or the heat-utilizing device 14 may be adapted for using the pressure as well as the temperature of this hot outlet gas. Similarly, the cold-utilizing device 18 may, if desired, be so constructed as to make use of the pressure as well as the low temperature of the cold-outlet gas.

Referring now to Figure 2 as it is actually operated, as distinguished from the preliminary explanation above, there is shown at 1 a differentiator chamber provided with the cam-operated valves 10, 35, 36, 37, 38, and associated therewith a regenerator 39, through which pass alternately, in opposite directions, the cold-outlet gas from the valve 35 and part of the inlet gas from the constant-pressure source 4. The remainder of the inlet gas reaches the differentiating chamber 1 through the cam-operated valve 36. The hot-outlet gas through the valve 10 and the cold-outlet gas through the valve 35 both exhaust into the atmosphere, so that this apparatus may be termed an open-system arrangement as distinguished from a closed hot-system arrangement or a completely closed system as are certain of the embodiments illustrated in the parent application above noted.

The cycle of operations is a follows: Assume atmospheric pressure and normal temperature throughout, and all the valves closed. The cycle of operations begins with the first inflow during which the cam-operated valve 36 at the near or inlet end 8 of the differentiating chamber 1 is opened to admit air from the constant-pressure source 4. When the chamber-pressure reaches approximately half its maximum value (this fraction may be varied within wide limits) the valve 36 closes and during the next succeeding part of the cycle, which may for convenience be termed the second inflow, the valves 38, 35 are opened to admit air from the constant-pressure source 4, downward through the regenerator 39 to the chamber 1, raising the chamber-pressure to maximum. The cam mechanism now serves to close the valves 38, 35 and simultaneously to open the hot-outlet valve 10, and during the ensuing hot-outflow of the cycle, the hot air at the upper or far end 7 of the chamber escapes to the atmosphere until this gas, of progressively decreasing temperature as in the previous types of apparatus, reaches approximately normal temperature simultaneously with the drop of chamber-pressure to half-maximum or thereabouts. Then the cold-outflow takes place upon the closing of the valve 10 and opening of the valves 35, 37, permitting the cold air from the near or inlet end 8 of the differentiating chamber to pass upward through the regenerator to the atmosphere. This completes the cycle.

It will be noted that now instead of having all parts of the apparatus at room-temperature, the lowermost part of the regenerator has a temperature somewhat lower than before owing to the fact that during the cold outflow the cold gas passed first through this lowermost section of the regenerator, and, naturally, abstracted heat from the walls thereof, in its passage upward to an atmospheric exhaust at 37. It will be seen therefore that at the beginning of the second cycle the upper end of the regenerator is approximately at room temperature, as before, while throughout the rest of the regenerator there is a progressively decreasing temperature reaching a minimum at the lower end 40. During the first inflow of the second cycle the air admitted through the valve 36 enters the chamber at room temperature and during the second inflow is pushed with a piston-like action toward the far or hot end 7 of the chamber by the entrance of inlet air which has passed downward through the regenerator on its way to the near end 8 of the chamber. Remembering now that the regenerator is progressively cooler toward the bottom, it will be seen that the air admitted during the second inflow is progressively cooled as it passes downward through the regenerator and that it enters the differentiating chamber at a temperature below normal. Since this air that is thus admitted is the air that issues during the cold-outflow, the importance of having it precooled will be appreciated; for by virtue of this precooling, this air issung during the cold-outflow of the second cycle is colder than the air issuing during the cold-outflow of the first cycle, because it was pre-cooled, while the corresponding air of the first cycle was not pre-cooled. This means that the regenerator temperature will be lower, and that during the second inflow of the third cycle the incoming air will be pre-cooled to a greater extent; from this it follows that the temperature of the air during the next cold-outflow will be lower, the regenerator cooled further, and finally as the regenerator becomes colder with each succeeding cycle of operations, a temperature at the coldest portion of the regenerator is reached that is sufficiently low for the liquefaction of air or for the particular purpose in hand, whatever it may be. By arranging the apparatus as above described so that the coldest section of the regenerator is at the bottom, the collection there of liquefied gas is facilitated and this liquefied product of the apparatus may be withdrawn through the valve 34. This self-intensifying action is augmented by having the regenerator operate with the hot and cold gases flowing in opposite directions.

The term "regenerator" mentioned above is employed herein to identify the heat-storing and -transferring devices referred to herein. This term has been adopted from the art of pre-heating furnace gases. The regenerator 39, for example, may comprise a chamber filled with substance such as shot or other material capable of taking up heat during the passage therethrough of relatively warmer gas, and giving off heat during the passage therethrough of relatively cooler gas. In this device the warm and cool gases pass through the regenerator alternately and in opposite directions. A recuperator, on the other hand, as described in connection with the parent application above noted, operates somewhat differently and comprises a chamber having two separate conduits for the relatively warm and cool gases, with the intervening space occupied by a substance capable of transferring the heat from the warmer to the cooler gas.

From the above description, taken in connection with the accompanying drawings, it will be seen that there is provided a number of types of apparatus adapted to fulfill the present-day engineering requirements of efficiency in cost and operation, and that by means of these illustrated embodiments of the invention the enumerated objects of the invention are attained and other advantages secured.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. Apparatus of the character described, comprising, in combination, a chamber, a regenerator, a source of fluid, means for admitting fluid from said source through said regenerator into said chamber, means for admitting fluid directly from said source into said chamber, means for abstracting fluid from said chamber, and means for abstracting the remaining fluid from said chamber through said regenerator.

2. Apparatus of the character described, comprising, in combination, a chamber, a regenerator, a source of fluid, means for admitting fluid from said source through one section of said regenerator to said chamber, means for admitting fluid from said source directly to said chamber, means for abstracting portions of the fluid from said chamber, and means for abstracting the remainder of said fluid from said chamber, said remainder being caused to pass through another section of said regenerator.

3. Apparatus of the character described, comprising, in combination, a chamber, a regenerator, a constant-pressure source of fluid, means for admitting during each cycle fluid from said source through said regenerator into said chamber at one end thereof, means for thereupon abstracting fluid from the other end of said chamber, and means for thereafter abstracting the remaining fluid from the first-named end of said chamber through said regenerator, said remain-

ing fluid passing through said regenerator in a direction opposite to the direction of travel of the inlet fluid therethrough.

4. Apparatus of the character described, comprising, in combination, a chamber, a regenerator, a constant-pressure source of fluid, means for admitting during each cycle fluid from said source through said regenerator into said chamber at one end thereof, means for thereupon admitting fluid directly from said source into said chamber at the same end thereof, means for thereupon abstracting fluid from the other end of said chamber, means for thereafter abstracting the remaining fluid from the first-named end of said chamber through said regenerator, said remaining fluid passing through said regenerator in a direction opposite to the direction of travel of the inlet fluid therethrough, and means for withdrawing at will the liquefied fluid from said regenerator.

5. Apparatus of the character described, comprising, in combination, means for disturbing the heat-content distribution in a fluid substantially adiabatically, means for separating the portion of increased heat-content from the remainder of the fluid, a regenerator, and means for passing the remainder of the fluid from said first means through said regenerator, whereby said remainder becomes progressively colder.

6. Apparatus of the character described, comprising, in combination, a chamber, a source of fluid, means for admitting fluid from said source to said chamber, means for exhausting from the chamber such portions of the fluid as may be caused to abstract from said chamber more heat than said portions had upon entering the said chamber, and means for thereupon emitting from said chamber through a self-intensifying regenerator such portions as may be caused to abstract from the chamber less heat than the said portions had upon entering.

7. Apparatus of the character described, comprising in combination, means for unbalancing the heat-content distribution in a fluid substantially adiabatically, means for separating prior to the equalization of the unbalanced heat-content, the fluid portion of increased heat-content from the remainder of the fluid, a regenerator, and means for passing therethrough the fluid portion of decreased heat-content.

8. Apparatus of the character described, comprising, in combination, a source of compressed fluid, heating means for said fluid comprising a device in which said fluid acts as a piston, a regenerator associated with said device, and means for passing fluid from said source through said regenerator to be cooled thereby and to said heating means.

9. Apparatus of the character described, comprising in combination, a source of compressed fluid, heating means for said fluid comprising a device in which said fluid acts as a piston, a regenerator associated with said device, means for passing a portion of the fluid admitted to said chamber through said regenerator to be cooled thereby, and means for passing a portion of the fluid discharged from said chamber through said regenerator at a lower temperature than the entering fluid.

10. Apparatus of the character described, comprising in combination, a source of compressed fluid, a container for fluid, an inlet and an outlet adjacent opposite ends of the container, a regenerator, an opening adjacent the same end of the container as the inlet and adapted for use as an outlet as well as an inlet, a connection between said opening and said regenerator, a connection between said inlet and said source of compressed fluid, and means adapted to open in succession said inlet to admit fluid from said source, said opening to admit fluid from said regenerator, said outlet to emit fluid, and said opening to emit fluid to the regenerator.

11. Apparatus of the character described, comprising in combination, a container for fluid, an inlet and an outlet adjacent opposite ends of the container, a regenerator, a connection between the regenerator and the inlet end of the container, and means adapted to open in succession said inlet to admit fluid, said connection to admit fluid from the regenerator, said outlet to emit fluid, and said connection to emit fluid to the regenerator.

12. In apparatus for utilizing fluids, means for causing differentiation of heat content in different parts of an integral body of fluid, so that one part thereof is heated and another part thereof is cooled, and means for segregating the hot and cold portions thereof, a regenerator, and means for passing part of the initial fluid through the regenerator and for passing said cold portion of the fluid through said regenerator.

13. In apparatus for obtaining extra-normal temperatures, means to effect, in recurring cycles, sequential substantially adiabatic compression and expansion of successive predetermined volumes of a homogeneous gas, a self-intensifying regenerator for progressively cooling a gas and means connecting said regenerator to said first-mentioned means adapted to pass said gas through said regenerator prior to compression and expansion by said means.

14. In apparatus for obtaining extra-normal temperatures, in combination, a chamber of fixed volume adapted for passage therethrough of a compressed gas, means to effect such passage, in cycles, with sequential substantially adiabatic compression and ex-

pansion in said chamber of each periodic charge of gas, a self-intensifying regenerator for progressively cooling a gas and means for passing said gas through said regenerator prior to its passage through said chamber.

15. The herein set forth method which includes compressing and expanding, in recurring sequence and substantially adiabatically, successive, substantially constant volumes of a fluid, and in utilizing cooled portions of the fluid to pre-cool a portion of the succeeding fluid to be compressed and expanded.

16. The method of obtaining sub-normal temperature, which includes, in recurring cycles, compressing and expanding gas in confinement, separating a predetermined portion which has undergone greater expansion than compression during such confinement, and in utilizing said separated portion to pre-cool a portion of succeeding gas to be compressed and expanded.

17. The herein described method which includes, in recurring cycles, admitting a compressed gas in two successive portions to a chamber, pre-cooling one of said portions of compressed gas prior to admission to the chamber, expanding the compressed gas admitted to said chamber, and separating for cold utilization a predetermined portion which has undergone greater expansion than compression during such confinement.

18. The herein described method which includes, in recurring sequence, compressing two successive portions of a gas and expanding the gas in confinement, separating a portion which has undergone greater expansion than compression during such confinement, and utilizing such portion to precool one of the two portions of succeeding gas to be compressed and expanded in confinement.

19. The herein described method which includes, in recurring cycles, compressing successively two portions of a gas and expanding the gas in confinement, separating for cold utilization a portion which has undergone greater expansion than compression during such confinement, passing said separated portion through a regenerator to abstract heat therefrom, and in passing one of the two portions of succeeding gas to be successively compressed and then expanded through said regenerator to pre-cool said last-mentioned portion of gas.

RUDOLPH VUILLEUMIER.