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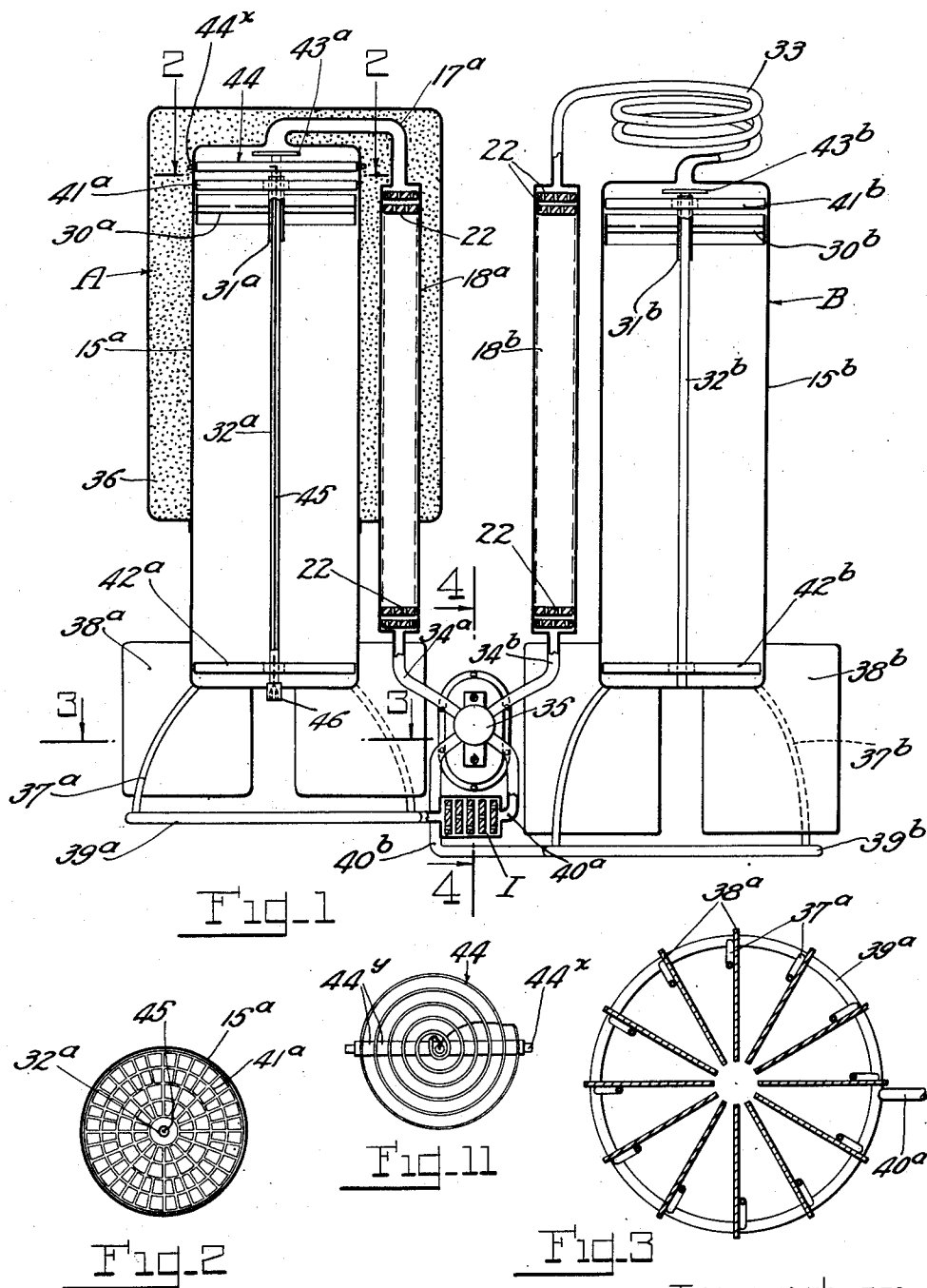
V. BUSH ET AL

2,175,376

METHOD OF AND APPARATUS FOR CONVERTING HEAT

Filed Nov. 21, 1935

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

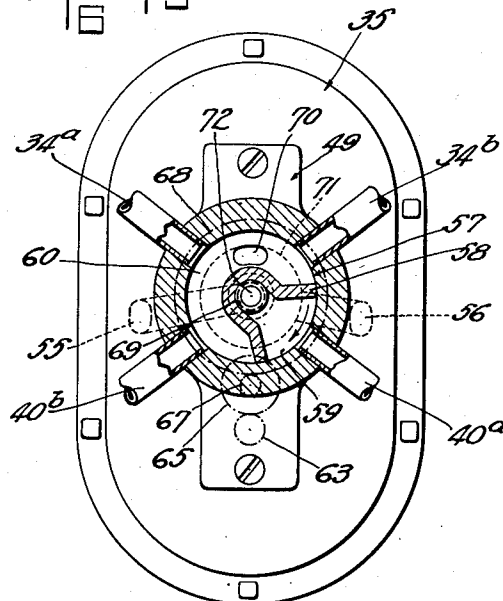
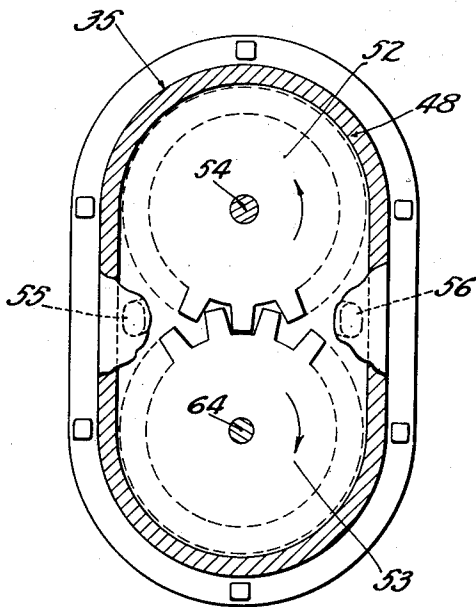
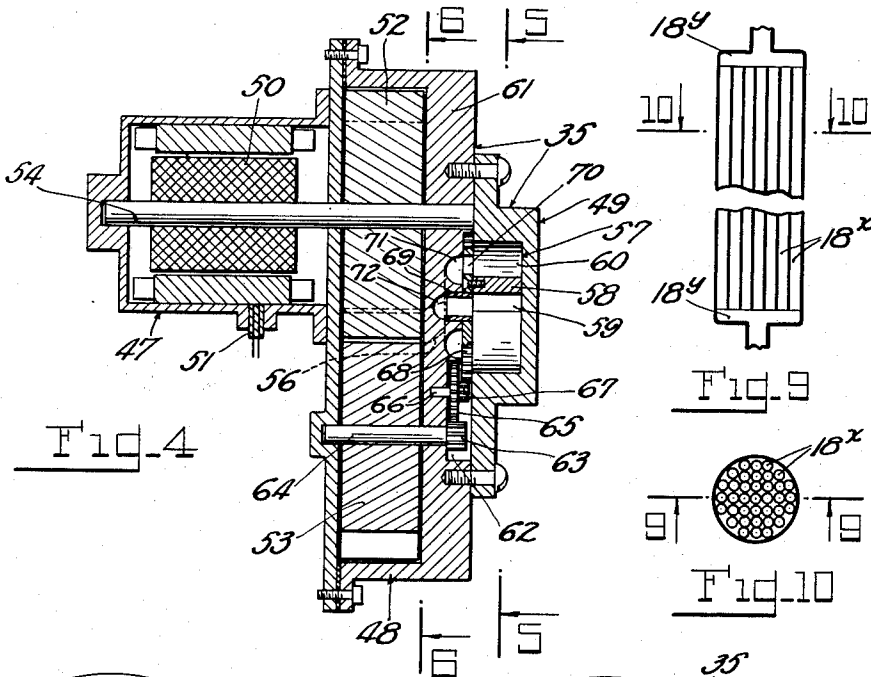


Fig-6

Fig-5

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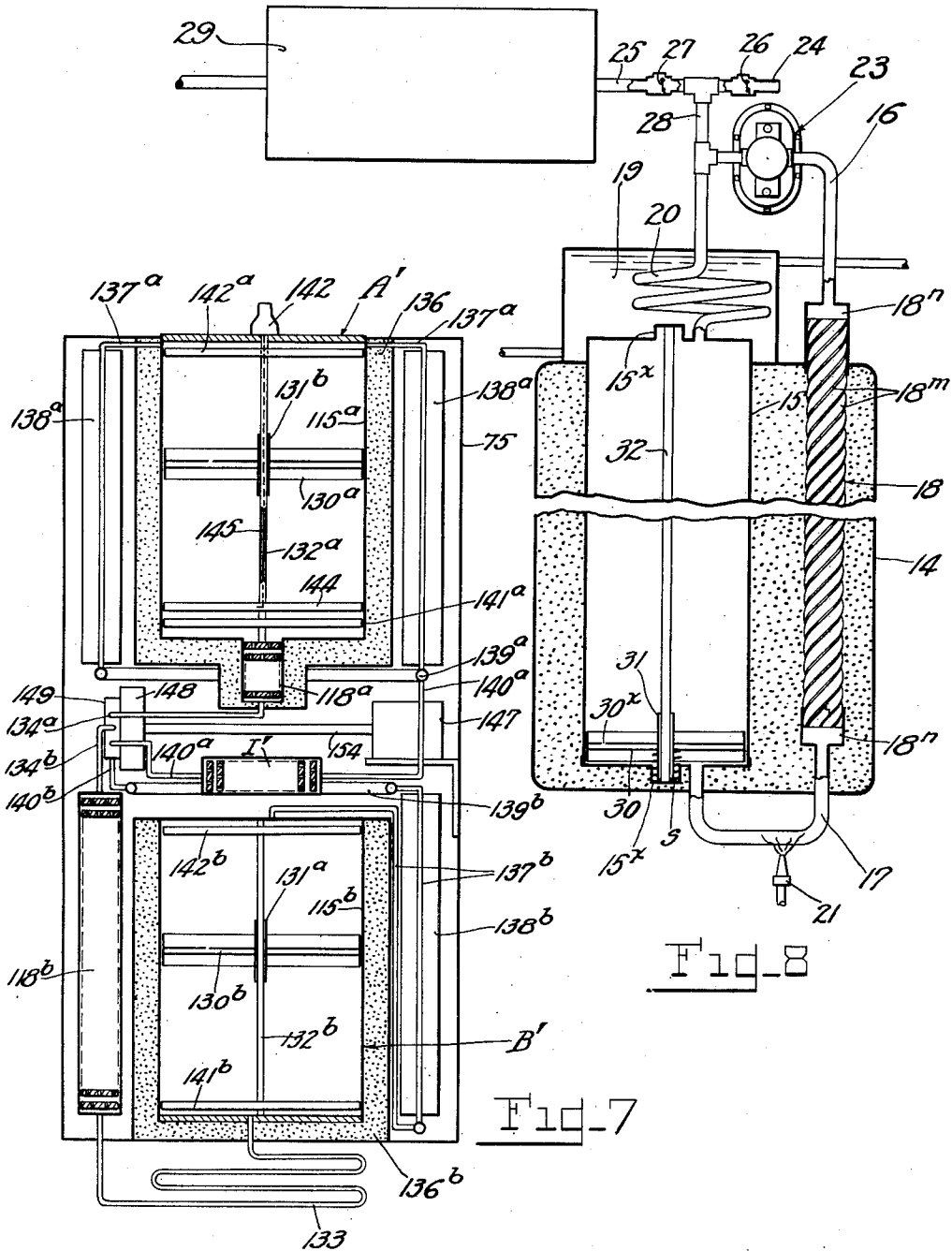
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METHOD OF AND APPARATUS FOR CONVERTING HEAT

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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,175,376

METHOD OF AND APPARATUS FOR
CONVERTING HEAT

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Application November 21, 1935, Serial No. 50,918

13 Claims. (Cl. 62—1)

In a prior application Serial No. 31,859, filed July 17, 1935, by Vannevar Bush, are described a method and apparatus for directly utilizing heat energy for the purpose of effecting the transfer of gas from a region of relatively low pressure to a region of relatively high pressure without the interposition of mechanical power, the apparatus employed being conveniently termed a "compressor" or "gas pump". In another application, Serial No. 45,553, filed October 18, 1935, now matured into Patent No. 2,127,286, by the same applicant, are described a method and apparatus for utilizing the same or similar principles to effect the transfer of heat from one region to another of higher thermal potential, that is to say, against the direction of normal heat flow, the apparatus employed being conveniently termed a "thermal pump". In accordance with the invention described in each of said applications, the energy employed for the accomplishment of the desired result is heat energy, as distinguished from mechanical energy, being developed by the intermittent flow of heat in the normal direction from a source, where it is generated or applied, to a sink, where it is dumped or dissipated. In each, a substantially constant volume of gas is alternately heated and cooled, thereby alternately raising and lowering its pressure. In the case of a compressor, these fluctuations in pressure are utilized to effect the transfer of gas between two regions of different pressure by admitting gas to the system from a region of low pressure when the pressure in the system is low, and ejecting gas from the system to a region of high pressure when the pressure is high. In the case of a thermal pump, the fluctuations in pressure are utilized to effect corresponding fluctuations in pressure in another but communicating body of gas from which heat is ejected to a region of high thermal potential when the pressure is raised and which is caused to absorb heat from a region of low thermal potential when the pressure is lowered.

In each of the several forms of apparatus described in the prior applications above referred to, the alternate heating and cooling of the gas is effected by moving or transferring it between two relatively hot and cold regions in a cylinder by means of a reciprocating member termed a "displacer". Also, in the case of the thermal pump, the transfer of the second body of gas between the heat ejection and heat absorption regions is effected by a similar displacer. Such a displacer has the additional function of providing,

in the cylinder, chambers of variable volume within which the gas meets walls of a substantially uniform temperature not greatly different at any time from that of the contained gas itself. In some instances, particularly in large installations where the ratio of volume to surface area is large, this second function can be economically dispensed with without substantial loss of efficiency, and other advantages thereby secured. In accordance with the present invention, the displacers of the prior applications are replaced by other gas moving means, for example, a continuously operating rotary blower with suitable provision for reversing the direction of circulation at the proper times. This has the advantage that the gas impelling means may be small, since it acts upon relatively small portions of the gas in sequence instead of acting upon substantially the entire body of gas affected at once. Also, instead of merely transferring the gas to the several regions (i. e., the heated region, the cooled region, the heat ejection region, and the heat absorption or refrigerated region), it is caused to flow through said regions to suitable storage spaces. Consequently, the heated region may be small, and the heat transfer to and from the other regions can be more effectually accomplished. Moreover, since, in the case of the thermal pump and that of the multi-stage compressor, only one movement of the gas need take place at one time, one blower, continuously operated, with suitable valves and connections, may be made to provide for all needed gas motions, although in both of these cases it is sometimes desirable to use separate blowers in order to more readily use different volumes of the separate storage spaces. The driving motor for such a blower may be located within the gas space, so that the apparatus may be hermetically sealed.

The foregoing and other objects and advantages of the invention will best be understood from the following description of the construction, arrangement and operation of certain forms of apparatus, illustrated in the accompanying drawings, in which it may be embodied and by which it may be practiced, these, however, having been chosen for purposes of exemplification merely, it being obvious that the invention, as defined by the claims hereunto appended, may be otherwise embodied and practiced without departure from its spirit and scope.

In said drawings:

Fig. 1 is a vertical sectional view, largely diagrammatic, of a thermal pump embodying the invention.

Figs. 2 and 3 are sections taken substantially on the lines 2—2 and 3—3, respectively, Fig. 1.

Fig. 4 is an enlarged section taken substantially on the line 4—4, Fig. 1.

Figs. 5 and 6 are sections taken substantially on the lines 5—5 and 6—6, Fig. 4.

Fig. 7 is a view similar to Fig. 1 showing an alternative arrangement.

Fig. 8 is a simplified diagrammatic view of a single unit, illustrating the principles of the invention as applied to a compressor.

Figs. 9 and 10 are longitudinal and transverse sections, respectively of an alternative form of regenerator.

Fig. 11 is a plan view of the heater shown in Fig. 1.

Referring first to Fig. 8, there is shown therein an apparatus which comprises a cylinder or chamber 15 connected at its upper and lower ends, respectively, through pipes or conduits 16 and 17, with the upper and lower ends of a regenerator 18, thereby constituting a closed circuit or system containing a substantially constant volume of gas the major portion of which is enclosed in said chamber 15. The portion of the conduit 16 adjacent the cylinder 15 is arranged in the form of a coil 20 located within a water jacket 19, whereby gas entering said cylinder through said conduit is cooled. The cylinder 15, regenerator 18, and water jacket 19 are preferably enclosed in an insulating jacket comprising an outer casing 14 filled with suitable insulating material, such as lampblack. The conduit 17 is locally heated, as by a suitable burner 21. The regenerator 18 comprises a plurality of loosely intertwined tubes 18 m each embedded in the insulating jacket and all connected to common headers 18 n , said tubes being composed of suitable material, such as stainless steel, capable of receiving and giving up heat rapidly but of low thermal conductivity, thereby providing a thermal gradient along the length of the regenerator, without serious loss due to heat conduction between the ends thereof. Alternatively, and as shown in Figs. 9 and 10, the regenerator may, in some cases, comprise a simple bundle of straight parallel tubes 18 x of suitable material connected to common headers 18 y . Located at some point in the circuit or system, for example in the conduit 16, is a blower 23 for maintaining a substantially continuous circulation of gas therein, means being provided for periodically reversing the direction of flow. This may be accomplished by employing a rotary blower with means for periodically reversing its direction of rotation or (in the case of a fan blower) the angle of its blades, or by employing such a blower together with a suitable reversing valve, as hereinafter more fully explained. Also communicating with the system at suitable points are inlet and outlet passages 24 and 25 controlled respectively by inlet and outlet valves 26 and 27. As shown, these passages communicate with the conduit 16 through a branch 28. The outlet passage 25 communicates with a region of relatively high pressure, such as a high pressure reservoir 29, and the inlet passage 24 with a similar low pressure reservoir or with the atmosphere or other region of relatively low pressure, depending upon the use to which the apparatus is to be put. Within the cylinder 15 is a separator 30 whose function it is to prevent relatively hot and cold gases from mixing, but which may, in some instances, be dispensed with, particularly if the cylinder be inverted to locate the cooled conduit at the bottom

and the heated conduit at the top. The separator consists of a very light metal or insulating member slidably mounted by means of a sleeve 31 upon a central guide rod or tube 32 and having a small clearance between its peripheral edge and the wall of the cylinder. The bearing of the sleeve 31 upon the tube 32 is suitably lubricated as by a graphite lining. The ends of the cylinder 15 are preferably provided with recesses 15 x to receive the ends of the sleeve 31 when the separator is in its extreme position and thereby reduce waste space. Said separator is preferably formed with double walls with a small gas space between and perforated at 30 x to equalize internal and external pressures and prevent collapse. Due to its very light weight, it is readily moved or blown upwardly by the gas when the latter enters the bottom of the cylinder through the conduit 17 and downwardly when gas enters the top of the cylinder through the conduit 16. If desired, a light spring s may be provided for the separator to contact with as it approaches the end of its downward movement and thus provide a slight impulse tending to keep it in correct mean position.

The cycle of operations of this unit is as follows: Starting with the separator 30 at the bottom of the chamber 15, as shown, and with both valves 26 and 27 closed, the blower 23 is operated to circulate the gas in the system in a clockwise direction, drawing cool gas from the upper end of the chamber through the conduit 16 and passing it downwardly through the regenerator 18, where it absorbs a certain amount of heat, thence through the conduit 17, where it is further heated by the burner 21, and finally into the lower end of the chamber, forcing the separator 30 upwardly. The chamber is thereby gradually filled with heated gas, so that the average temperature of the gas contained in said chamber gradually rises, and, since the volume of the entire system, and consequently of the total body of gas therein, is fixed or constant, the pressure of said gas rises. At a definite point in the course of the circulation of the gas in this direction, the pressure equals or slightly exceeds the pressure in the reservoir 29. The outlet valve 27 then opens, and, as the circulation of the gas in the clockwise direction continues, the pressure remains nearly constant, except as the reservoir pressure increases slightly, and gas is forced through the outlet passage 25 into the reservoir. When the chamber has been substantially completely filled with heated gas, the direction of circulation is reversed, drawing gas from the lower end of the chamber through the conduit 17 and passing it upwardly through the regenerator 18, when it gives up the greater part of its heat, and thence through the conduit 16, where it is further cooled, and into the upper end of the chamber, the separator 30 moving downwardly. The chamber is thereby gradually filled with cool gas which causes a decrease in the pressure in the system. With the initial drop in pressure to an amount equal to or slightly less than that in the reservoir, the outlet valve 27 closes; and when it is further reduced to an amount equal to or slightly less than that of the region with which the inlet passage 24 communicates, the inlet valve 26 opens. Thereafter the pressure remains substantially constant due to the inflow of gas through said inlet passage and valve. These operations are repeated, the direction of circulation being periodically reversed, and the chamber 15 being filled with heated and cooled gas alternately, thereby, since

the volume of the gas in the system as a whole is constant, causing periodic variations in the pressure thereof, and resulting in the transfer of gas from a region of low pressure through the inlet valve 26 to a region of high pressure through the outlet valve 27.

From the foregoing it will be seen that the compression or transfer of the gas is effected primarily and directly by heat energy, as distinguished from, and without the interposition of, mechanical energy or power. Although the apparatus includes certain mechanically operated moving parts, namely, the blower and the reversing valve, when the latter is used, these parts are merely for the control of the thermal cycle and do not operate against any considerable resistance. Since the system comprises a closed circuit, the pressures at the inlet and outlet sides, respectively, of the blower are substantially balanced, so that the gas imposes no considerable resistance to the operation of the latter but flows substantially freely about the circuit under its impulse. Consequently, the only force required to operate these controlling parts is that necessary to move the very light separator 30 and to overcome gas friction and such mechanical friction as may develop in the parts themselves, all of which are relatively small.

The general principles utilized in the apparatus above described for the purpose of transferring gas from one region to another of higher pressure, that is to say, against the direction of normal gas flow, can also be utilized for the purpose of transferring heat from one region to another of higher thermal potential, that is to say, against the direction of normal heat flow. An apparatus for effecting the latter result, and designed for refrigerating purposes, is shown in Fig. 1. Said apparatus comprises two units A and B which, for convenience, may be termed the power or compressor unit and the refrigerator unit, respectively. The unit A comprises a cylinder 15a, preferably of stainless steel, and a regenerator 18a, corresponding, respectively, to the cylinder 15 and regenerator 18 of the apparatus above described and connected at their upper ends by a conduit 17a. In this construction, however, the regenerator 18a comprises a cylinder containing spaced, perforated, aluminum or copper disks 22, the perforations in adjacent disks being staggered, and the space not filled by the disks being relatively small. The unit B comprises a similar cylinder or chamber 15b and regenerator 18b connected at their upper ends by a heat absorber or refrigerating coil 33, preferably formed from a flattened tube. The lower ends of the regenerators 18a and 18b, respectively, are connected by conduits 34a and 34b with a combined blower and valve casing 35, as hereinafter further described. The conduit 17a and the upper ends of the cylinder 15a and regenerator 18a are preferably enclosed by an insulating jacket comprising an outer casing 36 sealed at its lower end to the cylinder and regenerator, the intervening space being filled with a suitable insulating material, such as lamp-black.

Communicating with the lower end of the cylinder 15a are the upper ends of a plurality of curved, radially disposed heat exchange pipes 37a (see also Fig. 3) soldered to similarly disposed cooling fins 38a and communicating at their lower ends with an annular header 39a which, in turn, communicates, through a conduit 40a including an intermediate regenerator

I similar to the regenerators 18a and 18b, with the casing 35. Similarly, the lower end of the cylinder 15b communicates, through heat exchange pipes 37b soldered to cooling fins 38b, with an annular header 39b which, in turn, communicates, through a conduit 40b, with the casing 35. The temperature range between the several regions of the unit A is greater than that between the several regions of the unit B, so that it is permissible to employ a higher temperature, as compared to the air temperature, in the cooled region of the unit A, constituted by the heat exchange pipe 37a, than is permissible in the heat ejection region of the unit B, constituted by the heat exchange pipes 37b. The cooling fins 38a may therefore be smaller than the cooling fins 38b. In the operation of the apparatus, there is a certain amount of flow back and forth between the units A and B, due to fluctuations in pressure as hereinafter explained, and, in the course of this flow, the gas gives up a portion of its heat to the intermediate regenerator I in passing therethrough toward the right in Fig. 1, and absorbs heat therefrom in passing therethrough in the opposite direction.

Within the cylinders 15a and 15b in the construction shown, are separators 30a and 30b similar to the separator 30 and like it having sleeves 31a and 31b guided on central guide rods or tubes 32a and 32b.

Located in the upper and lower ends of the cylinders, adjacent their points of communication with the pipes or conduits 17a, 33, 37a and 37b, respectively, are honeycomb baffles 41a, 41b, 42a and 42b for producing parallel or lamellar flow and preventing turbulence. These comprise (see also Fig. 2) circular grids or plates of thick sheet metal of sizes corresponding to the cross sections of the cylinders, having central openings to receive the sleeves 31a and 31b, and perforated to form parallel holes of angular cross section to cause the gas to flow parallel to the axes of the cylinders and at substantially uniform velocities across their cross sections, the metal portions separating the perforations being thin to offer as little resistance as possible to the flow of gas while permitting the grids to perform their intended function. This effect may be further enhanced, at the ends of the cylinders which communicate with the conduit 17a and refrigerating coil 33, by the use of additional baffle plates 43a and 43b which act to distribute the inflowing gases across the cross section of the cylinders. Either the honeycomb baffles or the separators may be omitted, although the use of both is preferred. If the separator 30b be omitted, the refrigerator unit B should be inverted to locate the heat exchange pipe 37b and cooling fins 38b at the top and the refrigerating coils 33 at the bottom.

Located at the upper end of the cylinder 15a, preferably between the baffles 41a and 43a, is an electric heater 44 (see also Fig. 11) comprising a flat ribbon of a suitable heater alloy arranged in the form of a spiral, supported by a transverse rod 44x having porcelain spacers 44y between the convolutions of the spiral, and connected with lead wires 45 which, suitably insulated as by a porcelain tube, pass downwardly through the guide tube 32a and out through a suitably sealed outlet 46 in the lower end of the cylinder. This spiral is so shaped as to assist the baffle 41a in producing parallel flow, and may even replace the latter for this purpose.

Referring to Figs. 4, 5 and 6, the casing 35

comprises three sections 47, 48 and 49 and is totally enclosed and may be hermetically sealed by soldering the joints between the sections after assembly. The section 47 encloses an electric motor 53 the lead wires to which are brought out at a sealed outlet 51. The section 48 encloses a pump or blower which, as shown, is of the ordinary gear pump type comprising two gears 52 and 53 one of which may be of steel and the other of impregnated fibrous material such as is commonly used in gears to reduce noise. The gear 52 is fast on the armature shaft 54 of the motor 50, and the casing section 48 is provided with suitably located outlet and inlet ports 55 and 56. The section 49 encloses a circular valve chamber 57 having about its circumference four equally spaced ports with which the conduits 34a, 34b, 40a and 40b communicate, and in which is located a rotary valve element 58 so shaped, as shown in Fig. 5, as to divide the chamber 57 into two spaces or regions 59 and 60. The wall 61 of the casing section 48 adjacent the section 49 is formed with a recess or gear space 62 in which is located gearing for slowly rotating the valve element 58. Said gearing comprises a pinion 63 fast on the shaft 64 of the pump gear 53 which meshes with a gear 65 having a shaft or trunnion 66 journaled in the wall 61 and also having associated therewith a coaxial pinion 67 which meshes with a gear 68 having a hollow shaft or trunnion 69 likewise journaled in the wall 61. The valve element 58 is riveted or otherwise secured to the face of the gear 68 which is formed with a port 70 communicating with the valve space or region 60 and with an annular recess 71 formed in the adjacent face of the wall 61 and which, in turn, communicates with the inlet port 56. The port 70 and recess 71 are so located that they do not register or communicate with the portion of the gear space 62 containing the gears 63, 65 and 67. The valve space or region 59 communicates, through the hollow trunnion 69, with a recess 72 formed in the adjacent face of the wall 61 and which, in turn, communicates with the outlet port 55. The arrangement is such that the valve space 59 is in constant communication with the pump outlet and the valve space 60 in constant communication with the pump inlet, so that, as the valve element 58 is rotated, the conduits 34a, 34b, 40a and 40b will be successively connected with the pump outlet, the others being connected with each other and with the pump inlet, and the shape of the valve element 58 being such that it begins to open communication from the space 59 to one of said conduits just as it begins to close such communication to the previous conduit. Consequently, as the valve element 58 is rotated in a clockwise direction, as indicated by the arrow on Fig. 5, gas will be blown in sequence, and in the order named, into the top of the cylinder 15a, into the top of the cylinder 15b, into the bottom of the cylinder 15a, and into the bottom of the cylinder 15b. The effect of this cycle of operations is as follows:

Starting with the separators 30a and 30b in the upper ends of their respective cylinders, as shown in Fig. 1, and with the valve element 58 in the position to connect the conduit 34a with the valve space 59 and blower outlet 55, relatively cool gas is drawn from the lower end of the cylinder 15a (which at this time is in communication through the conduit 40a with the valve space 60 and blower inlet 56) and blown into the upper end of said cylinder, the separator 30a moving

downwardly. During this operation, the gas passes upwardly through the regenerator 18a, where it absorbs heat, and thence through the conduit 17a into the upper end of the cylinder where it is further heated by the heating coil 44. The cylinder 15a is thereby gradually filled with heated gas, so that the average temperature of the gas contained in said cylinder rises. Since the two units are at this time interconnected through the conduits 40a, 34b and 40b and valve space 60, and since the system is a closed one and the total volume of gas contained therein constant, the gas pressure in the whole apparatus, including the unit B, rises. The valve 58 then moves into the position to connect the conduit 34b with the valve space 59 and blower outlet 55, and the conduits 34a, 40a and 40b with the valve space 60 and blower inlet 56. Gas is thereupon drawn from the lower end of the cylinder 15b through the heat exchange pipes 37b, where the greater portion of its heat is ejected by the cooling fins 38b, and passed upwardly through the regenerator 18b, where it gives up additional heat, and through the refrigerating coils 33 into the upper end of the cylinder 15b, the separator 30b moving downwardly, so that said cylinder is gradually filled with relatively cool gas. The valve 58 then moves into the position to connect the conduit 40a with the valve space 59 and blower outlet 55 and the conduits 34a, 34b and 40b with the valve space 60 and blower inlet 56. Gas is thereupon drawn from the upper end of the cylinder 15a through the conduit 17a and downwardly through the regenerator 18a, where it gives up a portion of its heat, and is passed through the heat exchange pipes 37a, where it is further cooled by the fins 38a, the separator 30a being forced upwardly. The cylinder 15a is therefore gradually filled with cold gas, and the average temperature of the gas in said cylinder falls, so that the pressure in the system as a whole falls, and the gas in the cylinder 15b is expanded and further cooled or refrigerated. The valve 58 then moves into the position to connect the conduit 40b with the valve space 59 and blower outlet 55 and the conduits 34a, 34b and 40a with the valve space 60 and blower inlet 56. The refrigerated gas in the cylinder 15b is thereupon drawn from the upper end of said cylinder through the refrigerating coils 33, which are thereby refrigerated and enabled to absorb heat from the region to be cooled, and downwardly through the regenerator 18b, where it absorbs the heat given up during its upward passage, and is passed through the heat exchange pipes 37b into the lower end of the cylinder 15b, the separator 30b moving upwardly. Consequently the coils 33, and the region in which they are located, will be cooled or refrigerated. The valve 58 then moves into the position to connect the conduit 34a with the valve space 59, thereby completing the cycle.

The blower and reversing valve unit 23, above referred to in connection with the apparatus shown in Fig. 8, may obviously be substantially like that shown in Figs. 4, 5 and 6, except that the valve chamber 57 would be provided with two ports communicating respectively with the portions of the conduit 16 at opposite sides of the unit, and the valve element 58 so modified as to place these ports alternately in communication with the blower inlet and outlet, respectively. When a continuously operating positive blower, such as a gear blower, is used, extra ports should also be provided to permit the gas to be freely

circulated about a short path or by-pass during the intervals when the blower is not circulating gas through the system.

In each of the several forms of apparatus herein described, the heat exchange regions, such as the refrigerating coils 33, heat exchange pipes 37a, 37b, regenerators 18a, 18b, etc., are so designed with reference to the velocities employed as to give a Reynolds number above that representing the critical point of turbulence, so that the flow of gas through these regions is turbulent. By reason of this, as well as of the more or less tortuous forms of the paths traversed, the gas is brought into close thermal relationship with the several heat exchange elements, i. e., the walls of the several tubes or pipes, the regenerator elements, etc., and the rapid and efficient extraction and absorption of heat at the desired points thereby promoted. On the other hand, in the storage spaces, i. e., the cylinders 15a and 15b, the flow is slow and parallel or lamellar, due to the large cross section of the cylinders, the honeycomb baffles 41a, 41b, 42a, 42b, etc. Consequently, the amount of gas which is brought into thermal relationship with the walls of the cylinders is very small in proportion to the total volume of gas therein, there is no considerable heat interchange, and the gas at any time in a cylinder is thermally isolated therein and retains substantially the temperature at which it entered except for differences resulting from pressure changes. This result is enhanced by the fact that, due to the lamellar flow, and also, in part, to the action of the separators, there tends to form on the walls of the cylinders a more or less permanent, quiescent film of gas which acts as an excellent thermal barrier and is fully as effective as a wall of solid heat-insulating material. The great difference between the heat transfer resulting from the turbulent flow through small, tortuous, or subdivided passages in the heat exchange regions, and that resulting from the slow lamellar flow through the large cross section storage spaces, renders the apparatus described highly practical and efficient and makes possible the adoption of the blower circulating means described with the advantages above pointed out.

In Fig. 7 is shown, in simplified and diagrammatic form, a more compact arrangement, and one better suited to actual installation in certain situations, of apparatus otherwise substantially similar, as to its general organization and mode of operation, to the apparatus shown in Fig. 1. As shown in Fig. 7, the power and refrigerator units A' and B', respectively, are coaxially arranged within a cylindrical outer casing or housing 75, the power unit being at the top, and both units being inverted with respect to those shown in Fig. 1, so that the heated end of the unit A' and the refrigerated end of the unit B' are located at the bottom of the respective units. The motor 147, blower 148, valve 149, and intermediate regenerator I' are located between the units, and the refrigerator unit B' is enclosed in an insulating jacket 136b similar to the jacket 136 of the power unit A'. The remaining parts of the apparatus shown in Fig. 7 are indicated in said figure by the same reference numerals as the corresponding parts in Fig. 1, but with the numeral 1 prefixed in each case, and will, it is thought, be clearly understood without further description.

In a thermal pump of the character of those above described, the system being permanently closed and, if desired, hermetically sealed, it is

possible to employ pressures substantially higher than atmospheric and thereby obtain a large output with a given volume, and it is also desirable to use as a working medium a monatomic gas, such as argon or helium, of low molecular specific heat, all as more fully discussed in the prior applications above referred to.

We claim:

1. Thermal apparatus comprising a closed container having a plurality of relatively small volume regions at diverse temperatures and storage regions of relatively large volume, circulating means for transferring portions of the enclosed gas along paths within the apparatus in a repeated sequence, and means for establishing a turbulent flow of the circulating gas in the small regions and lamellar flow thereof in the large regions, whereby heat is caused to be transferred among the several small regions.

2. A thermal apparatus comprising means for containing a fixed volume of gas and including a region provided with means for establishing a substantially quiescent film of gas on the walls thereof and thereby thermally insulating the same, means for circulating said gas about said containing means in such a manner as to cause portions thereof to intermittently enter and leave said insulated region, and means for alternately heating and cooling gas entering or leaving said region.

3. In an apparatus of the character described, a gas containing system of substantially constant volume and including a chamber, a regenerator and conduits respectively connecting the opposite ends of said regenerator with said chamber, means for heating gas entering said chamber through one of said conduits, means for cooling gas entering said chamber through the other of said conduits, and gas circulating means for producing a substantially non-turbulent flow of gas into opposite ends of said chamber in alternation by circulating the gas alternately in opposite directions through said system, said gas circulating means comprising a continuously running blower and a distributing valve.

4. Thermal apparatus comprising a closed container having a plurality of relatively small volume regions at diverse temperatures and storage regions of relatively large volume, circulating means for transferring portions of the enclosed gas along paths within the apparatus in a repeated sequence, and means for establishing turbulent flow of the circulating gas in the small regions and lamellar flow thereof in the large regions, whereby heat is caused to be transferred among the several small regions, a part of this heat transfer being in the direction of increased thermodynamic potential.

5. A thermal pump comprising a gas chamber, two conduits communicating therewith, means for heating gas entering or leaving said chamber through one of said conduits, means for cooling gas entering or leaving said chamber through the other of said conduits, a second gas chamber, heat exchange conduits communicating with said second chamber and with said first named conduits, a blower, and a valve controlling communication of the blower inlet and outlet with said conduits for causing gas to flow into said first named chamber alternately through said two first named conduits and in alternating sequence for causing gas to flow through said second chamber and heat exchange conduits alternately in opposite directions.

6. A thermal pump comprising a gas chamber, a conduit communicating therewith, means for heating gas entering or leaving said chamber through said conduit, a second conduit communicating with said chamber, means for cooling gas entering or leaving said chamber through said second conduit, a second gas chamber, heat absorption and heat ejection conduits communicating with said second chamber, a blower, a valve casing having ports communicating with the several conduits, and a rotary valve in said casing adapted, when rotated, to place said first named conduit, said heat absorption conduit, said second conduit, and said heat ejection conduit, in the order named, in communication with the blower outlet and the remaining conduits in communication with the blower inlet.
7. A thermal pump comprising two closed gas containers one of which includes a heated region and a cooled region and the other of which includes a heat absorption region and a heat ejection region, a single gas-displacing means for acting in succession upon volumes of gas that are small in relation to the volumes of gas in the containers, each container including a chamber and conduits for providing communication between opposite ends of said chambers and said gas displacing means, and valve means controlling communication between the several conduits and said gas-displacing means for effecting a circulation of said gas in predetermined sequence through the several regions of both containers and for establishing continuous communication between the two containers.
8. A thermal pump comprising a closed system including two intercommunicating gas containers one of which includes a heated region and a cooled region and the other of which includes a heat absorption region and a heat ejection region, a blower for circulating gas about said system, and means for directing gas passing from said blower alternately in opposite directions and in a pre-

determined sequence through the several regions of both containers.

9. A thermal pump as claimed in claim 8, wherein said gas-directing means is a rotary valve mechanically driven by said blower.

10. A thermal pump as claimed in claim 8, wherein said gas-directing means is a rotary valve geared to said blower, said valve and blower having a common casing.

11. Thermal apparatus of the type including a closed container, a regenerator, circulating means for alternately passing gas from end to end of said container through said regenerator, and means for mechanically separating the bodies of gas of different temperature that occupy different ends of said container, characterized by the fact that said separating means comprises a lightweight separator and means guiding said separator for movement from end to end of said container, said separator being displaceable by the unbalanced pressures established at opposite ends of said container by said circulating means.

12. Thermal apparatus comprising a container of fixed volume, a regenerator, circulating means for alternately passing gas from end to end of said container through said regenerator, and means at opposite ends of said container for establishing a lamellar flow of gas in the same during movement of the gas by said circulating means.

13. In the operation of a constant volume thermal system of the type in which gas is alternately transferred from one end of a thermally insulated container to the other end through a regenerator, the method which comprises establishing a turbulent flow of gas through the regenerator to promote heat transfer, and establishing a lamellar flow of gas in the container to minimize a heat transfer.

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