Sept. 5, 1950 S. HOLM ET AL 2,521,369

MULTIFLUID HEAT EXCHANGER

Filed Nov. 3, 1944 3 Sheets-Sheet 1

Fig. 1

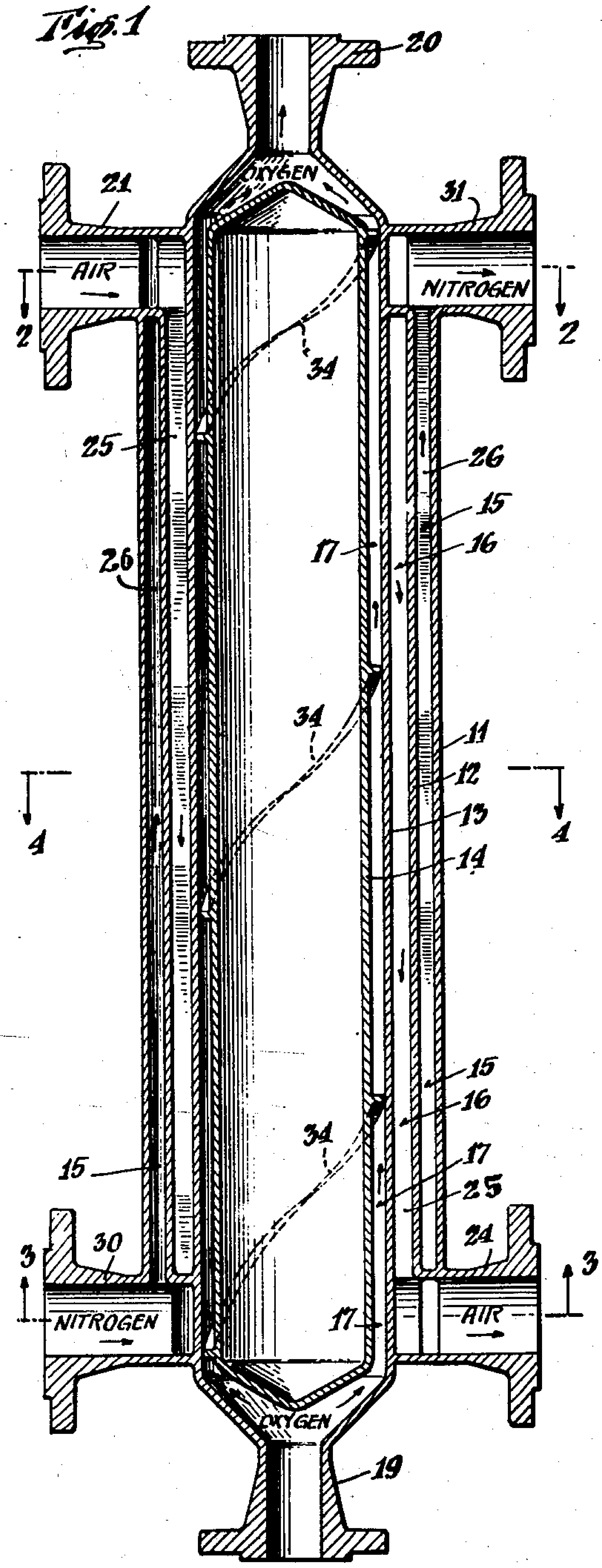


Fig. 2

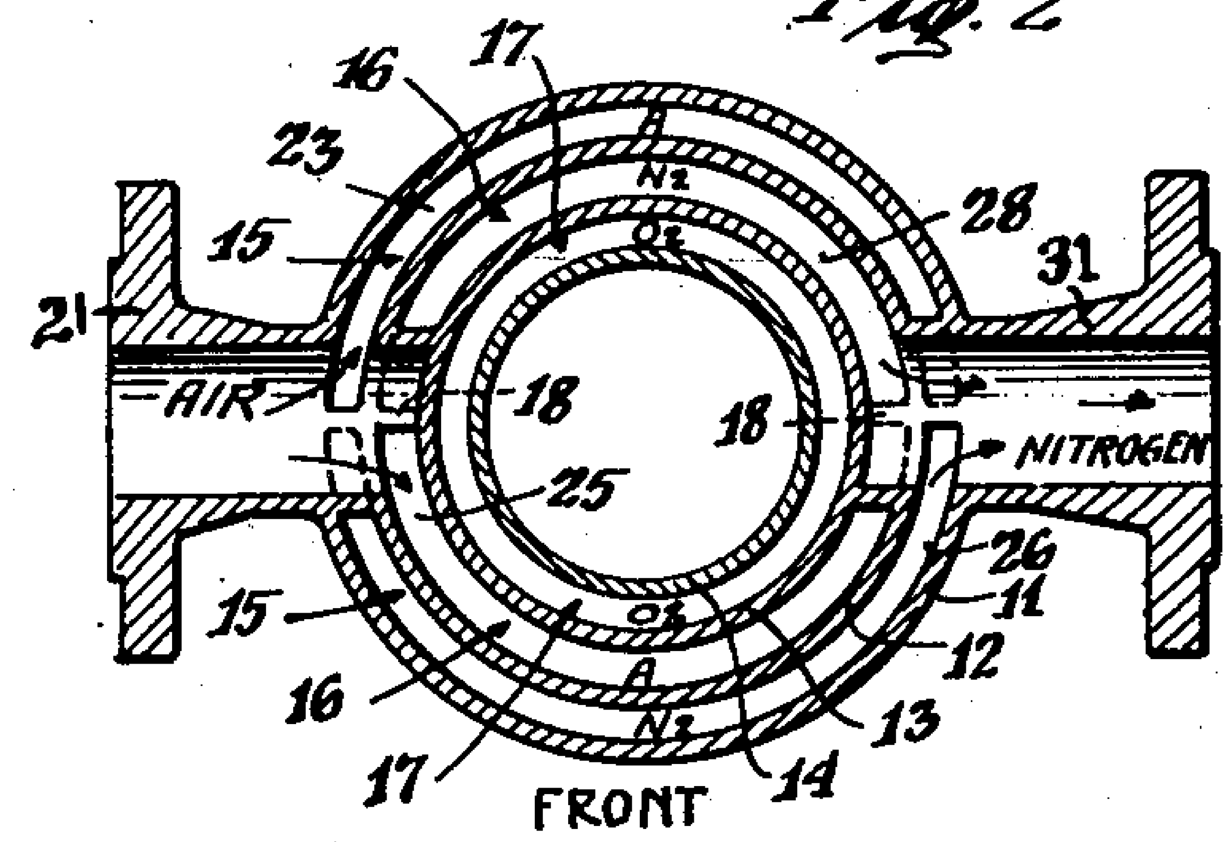


Fig. 3

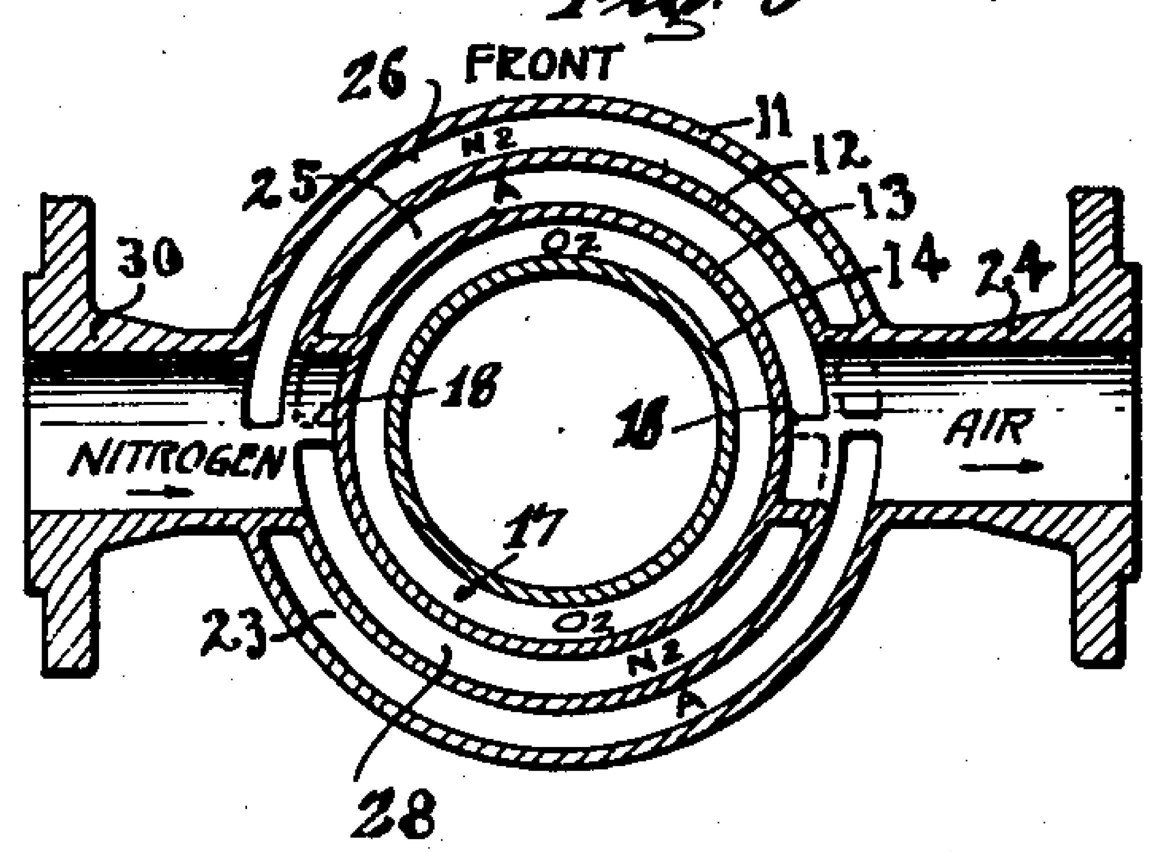


Fig. 4

CYCLE I

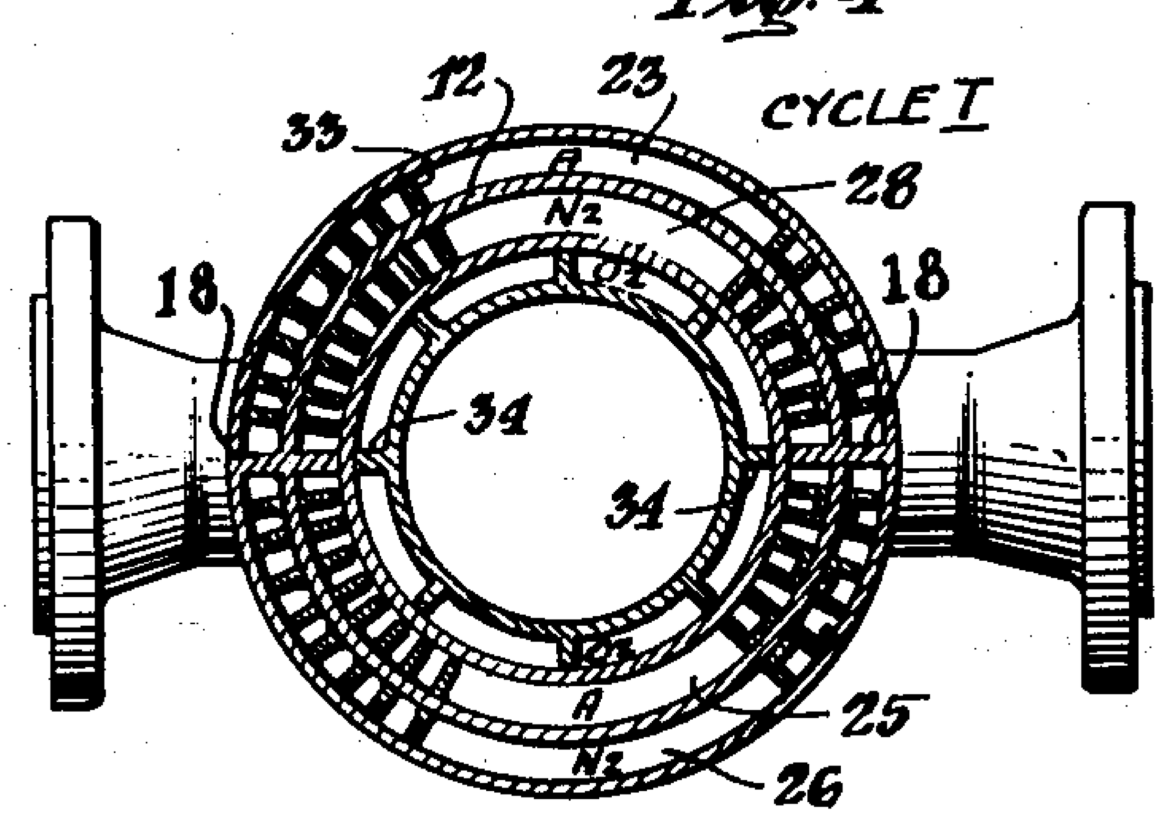
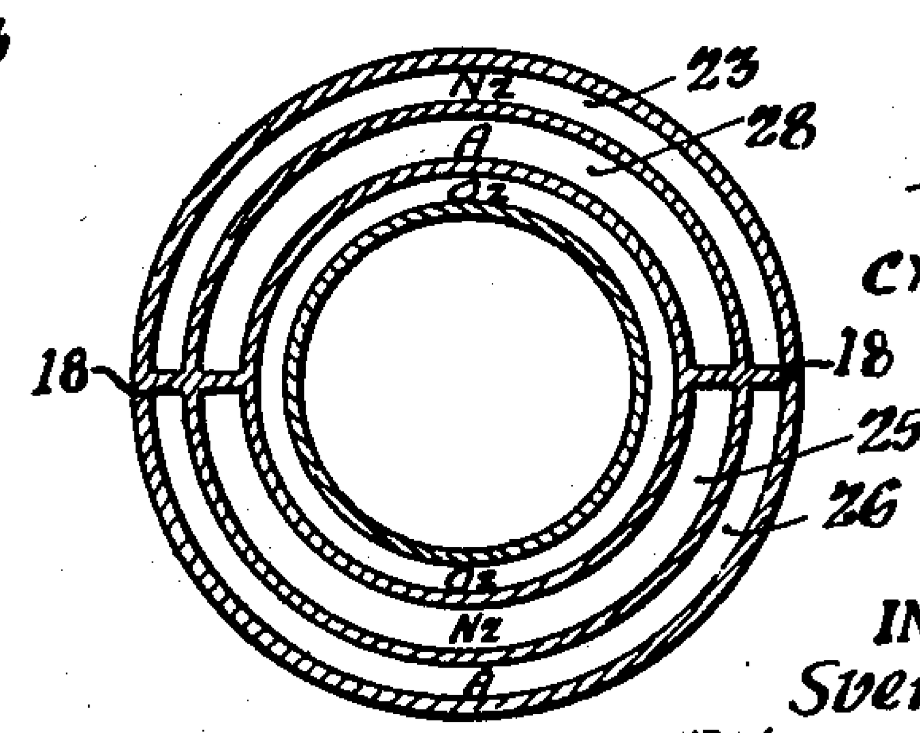


Fig. 4a

CYCLE II



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MULTIFLUID HEAT EXCHANGER

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Fig. 6

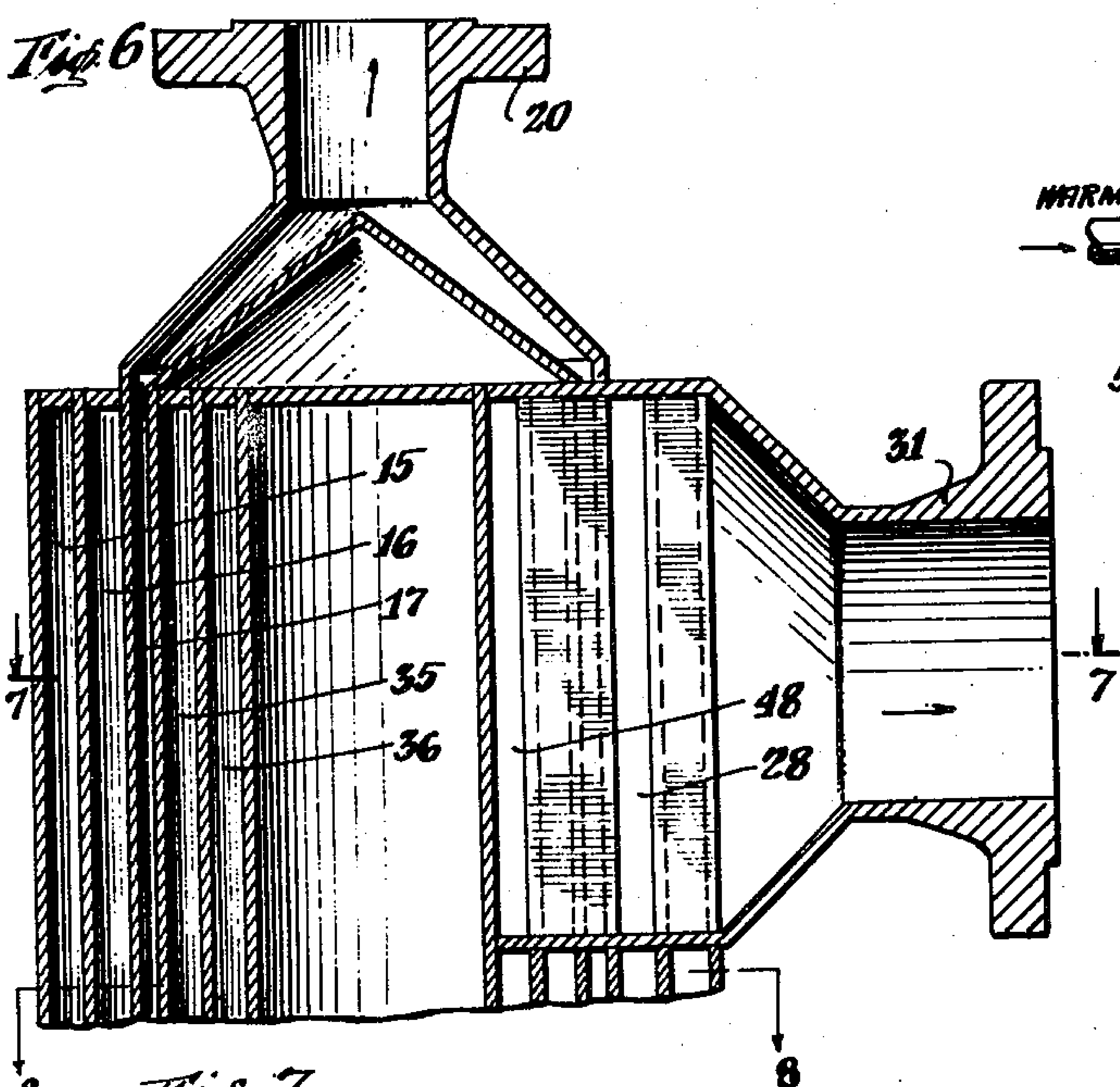


Fig. 5

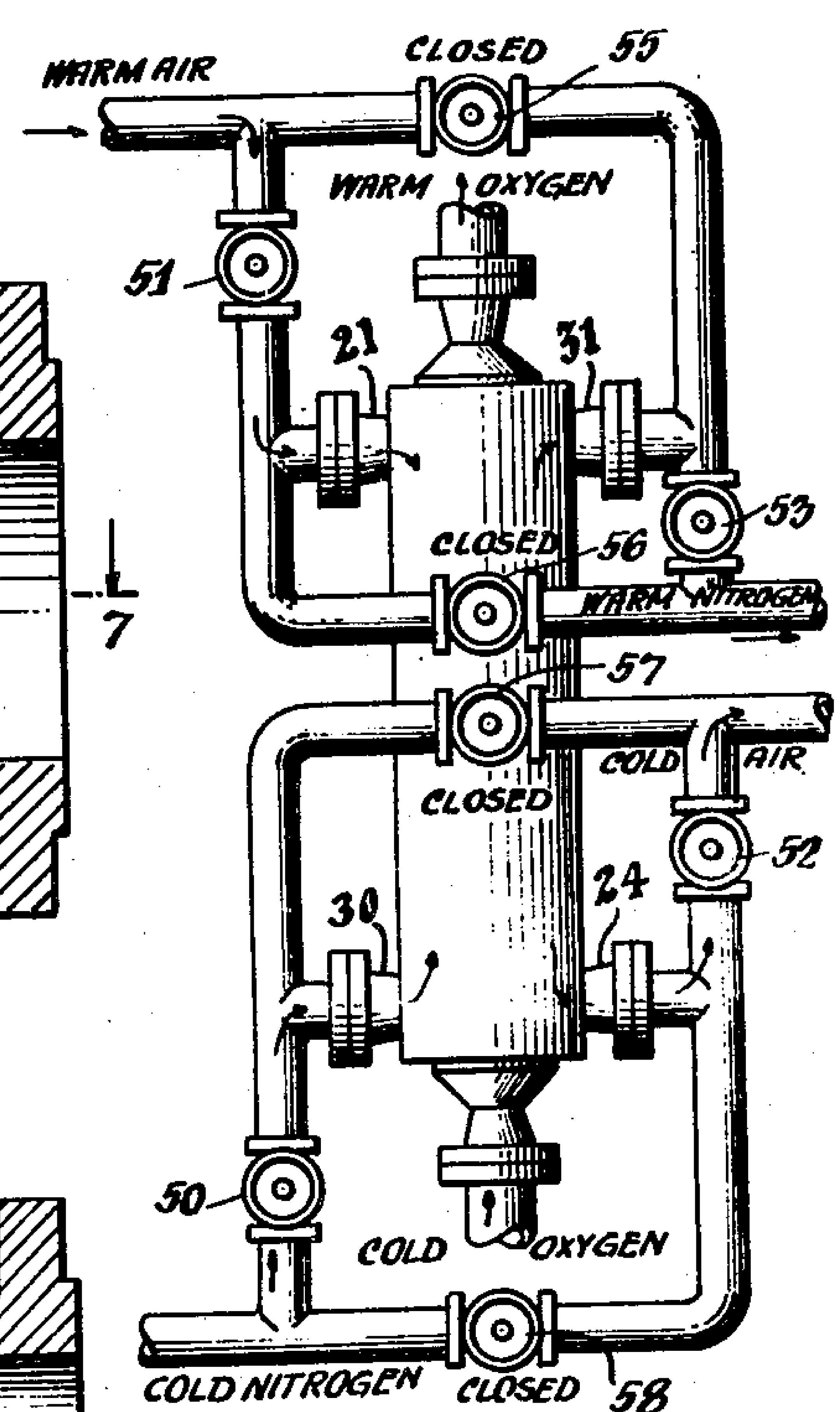
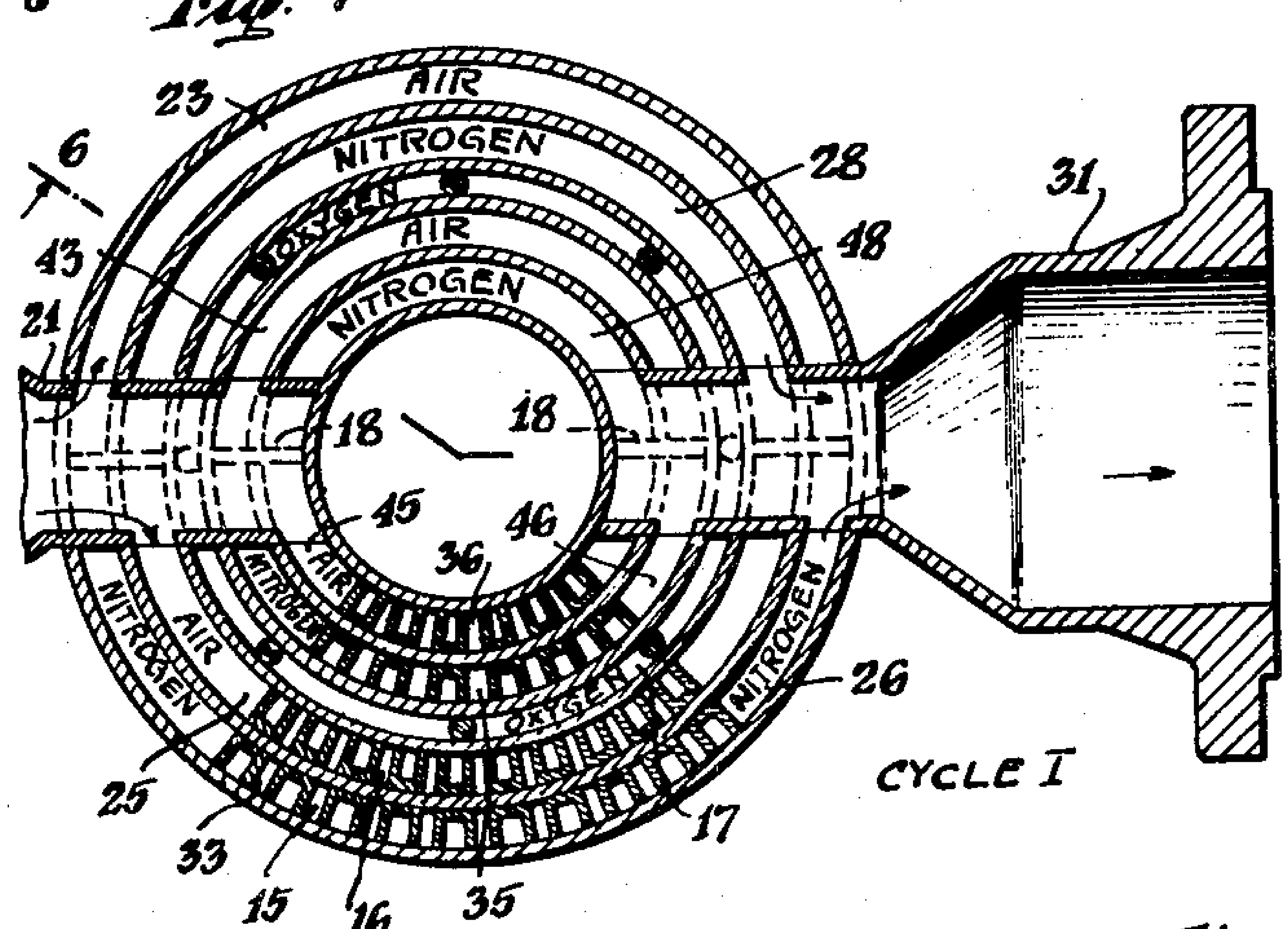


Fig. 7



CYCLE I

Fig. 8

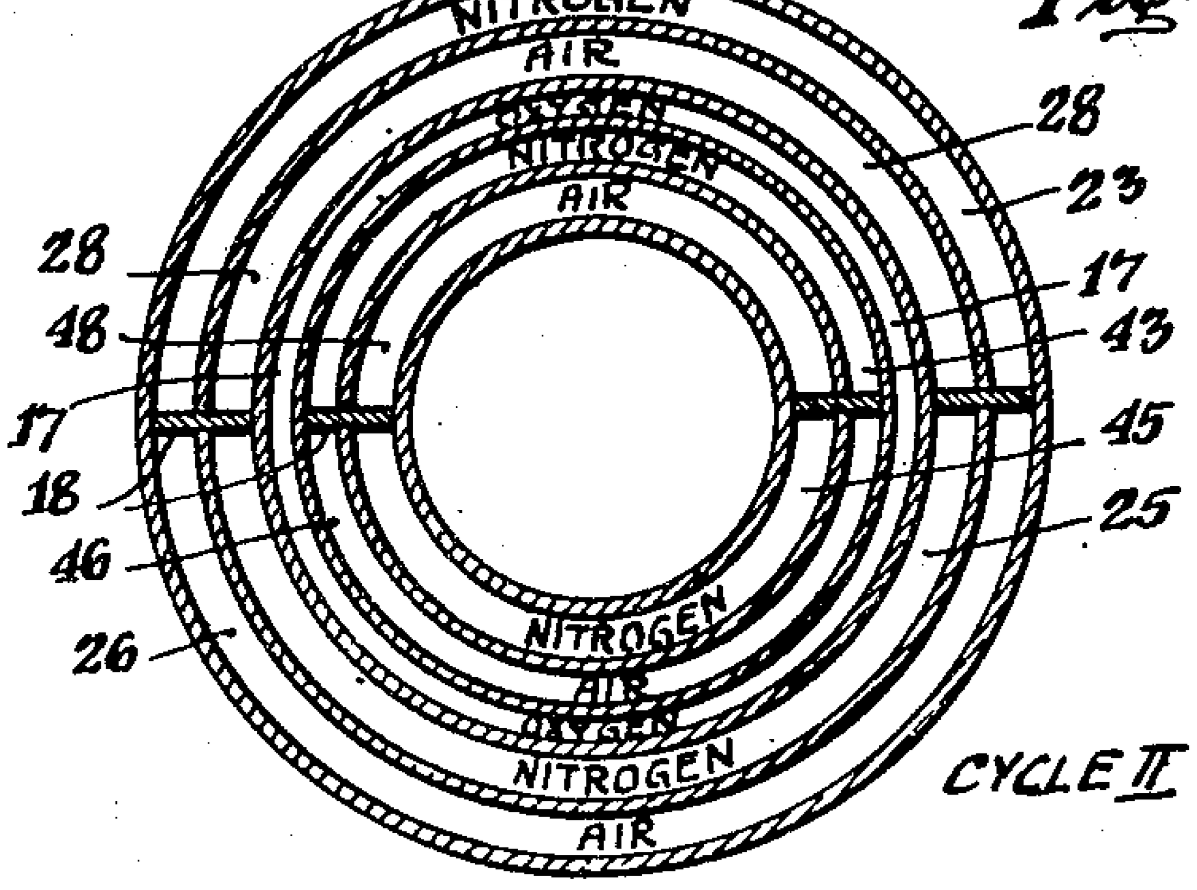


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Fig. 9.

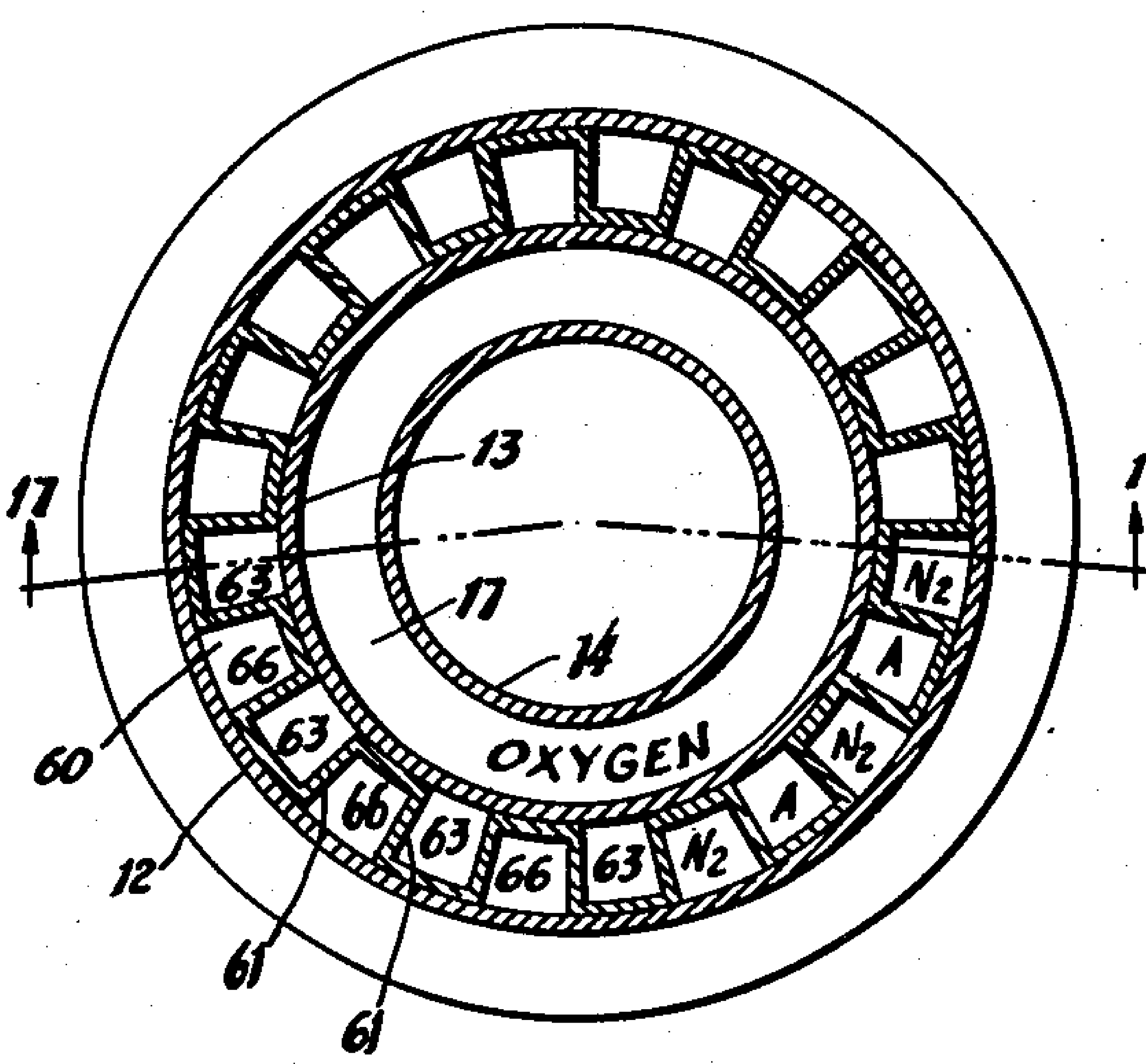


Fig. 11.

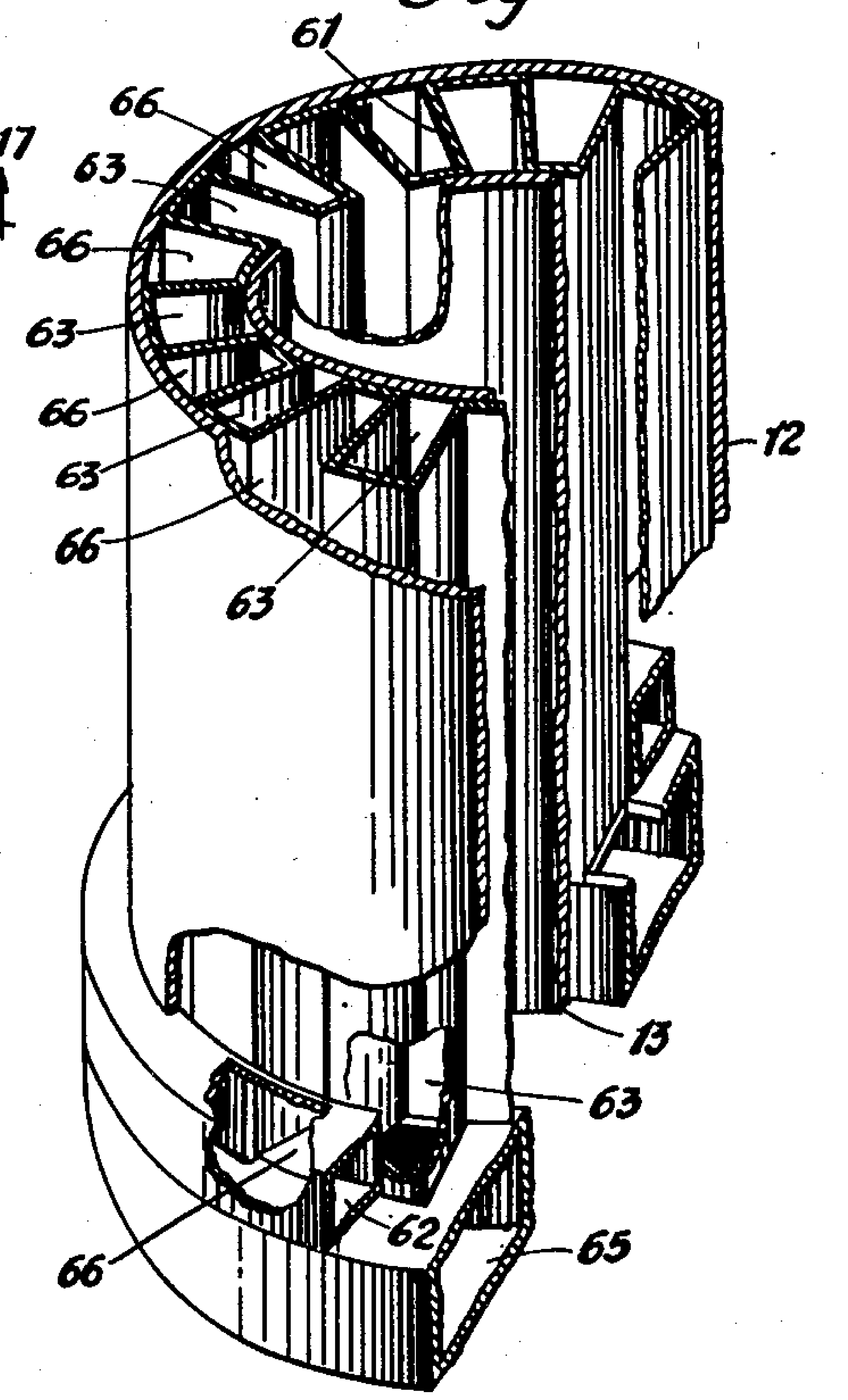
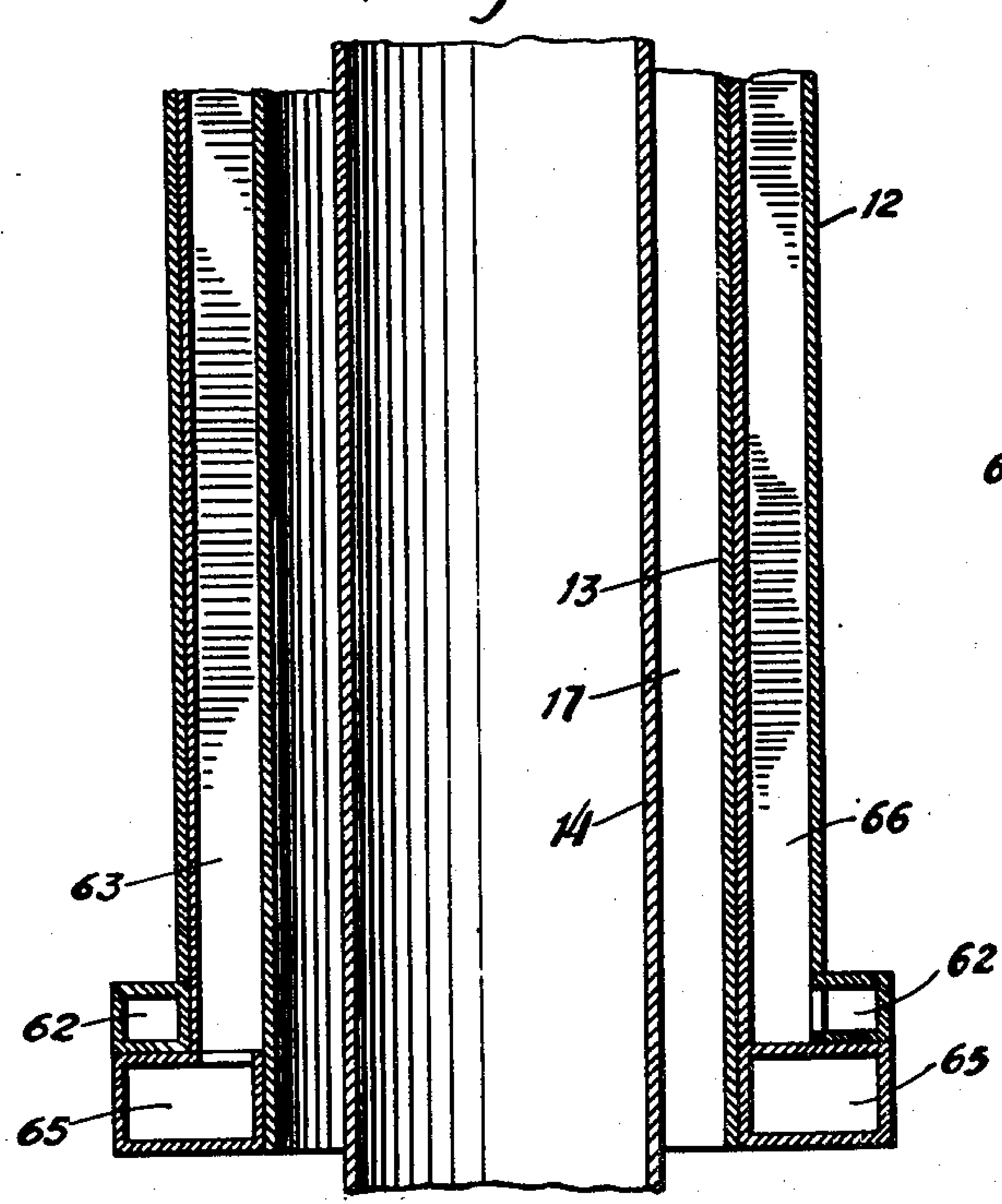


Fig. 10.



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Patented Sept. 5, 1950 2,521,369

UNITED STATES PATENT OFFICE

2,521,369

MULTIFLUID HEAT EXCHANGER

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Application November 3, 1944, Serial No. 561,766

12 Claims. (Cl. 257—246)

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The present invention relates to heat exchange apparatus and particularly to apparatus in which heat is transferred between three or more streams of fluid.

In the embodiments of the invention described herein the invention is incorporated in a plate type heat exchanger through the passages of which one fluid is circulated to be cooled by indirect contact with two other fluids.

One use contemplated for the apparatus is to cool air to very low temperatures using oxygen and nitrogen both at temperatures substantially below 0° F. The air entering at a temperature around 100° F. carries a certain amount of water vapor which sublimes to ice at low temperatures. To dispose of the ice it is necessary to transpose the air and nitrogen streams so that the nitrogen re-evaporates the ice deposited from the air. The apparatus, therefore, works in two cycles, each of which must give the same performance as to heat exchange and pressure drop. The oxygen enters the apparatus at a lower temperature than the nitrogen but is required to leave at the same temperature and, therefore, receives heat from both the air and the nitrogen.

A feature of the invention is a heat exchanger construction in which two of the streams of fluid may be switched or transposed with respect to their relation to each other without, however, changing the rate of heat transfer among the three fluids, the pressure drop through the exchanger for any fluid or the direction of flow thereof.

The invention will be best understood upon consideration of the following detailed description of illustrative embodiments thereof when considered in conjunction with the accompanying drawings, in which:

Figure 1 is a vertical sectional elevation of a heat exchanger embodying the invention in apparatus having a series of concentric annular passages;

Figures 2 and 3 are transverse sectional views along the correspondingly designated section lines in Figure 1 and illustrate the connections of inlet and outlet ducts with the passages of the exchanger;

Figures 4 and 4*a* are sectional views on line 4—4 of Figure 1 illustrating the flow of the fluids during the two cycles of operation of the apparatus shown in Figures 1 to 3.

Figure 5 is an elevational view of a heat exchanger embodying the invention and showing its relation to the supply and discharge ducts for the various fluids.

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Figure 6 is a fragmentary sectional view on line 6—6 of Figure 7 of the upper part of a heat exchanger like that shown in Figure 1 but having a larger number of passages;

Figure 7 is a sectional view partly on the line 7—7 in Figure 6, showing the connections of inlet and outlet ducts with the fluid passages and illustrating the first operating cycle;

Figure 8 is a sectional view on line 8—8 in Figure 6 and illustrates the flow of fluids through the apparatus during the second cycle of operation;

Figure 9 is a transverse sectional view showing another form of apparatus in which two of the fluids are circulated through a single annulus in which independent passages are formed; and

Figures 10 and 11 are a sectional elevation and perspective view showing connection of the passages of the apparatus in Figure 9 with either inlet and outlet headers for the fluids.

In Figures 1 to 3, the four concentric wall members 11, 12, 13 and 14 define a pair of adjacent annular passages 15, 16 extending longitudinally of the apparatus and a similarly disposed centrally located channel 17. One of the cooling fluids (oxygen) enters the central channel 17 at one end of the apparatus through an inlet connection 19 and is discharged from the opposite end of the exchanger through an outlet connection 20. As shown in Figures 2 and 3 each of the annular passages 15, 16 is divided into two semicircular parts by the diametrically located partitions 18; these annuli could be further subdivided if desired. At the upper end of the apparatus at the left hand side air to be cooled enters through an inlet connection 21 which communicates at the left hand or upper side of the partition 18 with the section 23 of the outermost annular passage 15 and at the right hand or lower side of Fig. 2 of the partition 18 with the section 25 of the inner annular passage 16. At the lower end of the apparatus the outlet connection 24 for air communicates in like manner with the lower ends of the semi-circular sections 23, 25, one in each of the two annuli. The cold nitrogen enters the bottom of the apparatus at the left hand side through an inlet connection 30 which extends toward the center of the apparatus but communicates at the right hand side of the partition 18 only with the section 26 of the outer annulus 15 and at the left hand side of the partition 18 with the section 28 of the inner annulus. At the upper right hand side of the apparatus the nitrogen is discharged through a similarly connected outlet 31 which communicates only with the upper ends of the semi-circular sections 26 and 28, one in each of the annuli 15, 16. With connections so arranged the air flows countercurrent with respect both to nitrogen and oxygen, which is the desired relationship for maximum heat transfer.

Fundamentally the apparatus comprises a plurality of adjacent parallel fluid passages. In the form to be described immediately these are in three concentric annuli. By covering the lower halves of the diagrams designated Figs. 4 and 4*a* it may be noted that if the air were to flow in the entire outer annulus in cycle I and in the intermediate annulus in cycle II, it is evident that the air would be cooled to a much lower temperature in cycle II, where it would flow between the cold oxygen and the cold nitrogen. Further, a discrepancy in the diameter of the annulae could also result in a difference in pressure drop due to difference in mass velocity. When nitrogen flows in the entire intermediate annulus in cycle I, the oxygen does not exchange any heat with the air in that cycle.

When in accordance with the invention the air and nitrogen streams each flow in one-half or other adjacent fractional sections of the same annulus separated by a dividing wall, the total flow area for each of the two gases is the same in both cycles and the entire apparatus is balanced as to heat exchange relationship in the two cycles since the relations that exist on one side in one cycle have their counterparts on the other side in the second cycle. Heat is also exchanged at the same rate between the three gases in either cycle. The air and nitrogen flow through the apparatus in substantially greater amount than the oxygen; therefore, extended surfaces in the form of fins 33 are used in the annulae 15, 16 carrying these gases. The hydraulic diameter of the channels between fins must be the same for air as for nitrogen because the pressure drop increases inversely as the hydraulic diameter. For pressure drop, the hydraulic diameter (also called equivalent diameter) is defined as equal to four times the area of channel divided by the circumference. In heat transfer the hydraulic diameter of a passage depends on what portion of its perimeter is effective as heat transfer surface, and is defined as four times the cross-sectional area divided by the portion of perimeter through which heat exchange takes place. The walls 11, 12, 13 and 14 are therefore spaced radially at such distances that the hydraulic diameter of the inner and outer annuli 15, 16 is the same. This applies also to Figs. 6 and 7 wherein the passages 16 and 36 are of greater radial width than passages 15 and 35 to obtain the same hydraulic diameter. For the same reason the fins are radially opposite each other in pairs, with the fins in passage 35 having the same spacing on the circumference as the fins in passage 15, and the fins in passage 36 spaced radially opposite fins in passage 35. The rate of heat transfer is inversely proportional to the two-tenths power of the hydraulic diameter. It is therefore evident that by off-setting the flow in the different annulae the two cycles are equal, whereas if one gas stream occupies an entire annulus the two cycles would not be equal because the outside of the apparatus is not a heat transfer surface. The heat loss from the outside through insulation (not shown) has the same effect on temperature of nitrogen and air in both cycles, as can be seen by study of Figures 4 and 4*a*, which

show that both of these gases contact the same portion of outside shell in both cycles.

The oxygen stream flows through the apparatus guided by one or more helically wound fins 34 to impart a swirling motion to the fluid, which thereby alternately passes over surface exchanging heat with air or nitrogen. This prevents any temperature stratification of the oxygen stream.

The construction shown in Figs. 6 and 7 embodies the same principles but has an additional pair of annular passages concentrically disposed inwardly of the oxygen channel 17. Thus there is an outer pair of annular passages 15, 16 outside of the channel 17 and an inner pair of passages 35 and 36 inwardly of the channel 17. The arrangements of the inlet and outlet connections for this apparatus are shown in Figs. 7 and 8 wherein an inlet connection such as that for air designated 21 extends across the upper ends of all the annular passages but communicates only with the alternate semi-circular sections 23, 43 at one side of the partition 18 and with the intermediate sections 25, 45 at the other side of the partition 18. Nitrogen flows in alternate sections 26, 46 and intermediate sections 28, 48. With this form there is complete balance of the heat transfer relation of the several fluids as may be noted by examining Figs. 7 and 8 showing the relationships for both cycles. The streams of nitrogen and air, respectively, are always in passages at opposite sides of an intervening wall while the oxygen flowing through the channel 17 always has a stream of air at one side and of nitrogen at the other. At the lower part of Fig. 7 the air is in the passage 25 outwardly of the channel 17, through which the oxygen flows and the nitrogen is in the inner passage section 46. The relation is reversed in the upper part (Fig. 7) of the apparatus where the nitrogen is in the outer passage section 28 and the air is in the inner passage section 43. When the air is caused to flow through channels previously filled with nitrogen and vice versa, the respective positions of these fluids with respect to oxygen are changed as indicated in Fig. 8 but the heat transfer relationships remain the same.

With supply and discharge piping connected as indicated in Fig. 5, all of the valves 50–53 are open when air flows through the passage sections 23, 25 (and 43, 45, also Fig. 8) in the first cycle and nitrogen flows through the sections 26, 28, 46, 48 while all the valves 55–58 are closed. Conversely, in the second cycle all of the valves 55–58 are open and valves 50–53 are closed when the nitrogen is to flow through the semi-circular sections 25, 23; (and 43, 45 also in Fig. 8). The relative countercurrent relation of the flow of air to nitrogen and oxygen is maintained in both cycles as the directions of flow are not changed.

In the construction diagrammatically indicated in Fig. 9 only one annular passage surrounds the channel 17 through which oxygen flows. This single annular passage, however, is divided by a number of closely spaced radial partitions 61 into any desired number of arcuate segments. The inlet and outlet connections to headers 62, 65 are arranged so that one fluid such as air flows through alternate passages 63 while the other, such as nitrogen, flows through the intermediate passages 66. It will be noted that the air is cooled by nitrogen flowing in intermediate channels at either side of its flow passages and also by the oxygen in the channel 17 at the inner side of the wall 13. When the valve connections are changed to circulate nitrogen through the alternate passages 63 and air through the intermediate passages 66 exactly the same heat transfer relationships exist among the three fluids.

It will be appreciated that all of the various forms of the invention described above embody the generic principle of cooling (or heating) one fluid by means of two others while providing for transposing the relations of the treated fluid and one of the treating fluids due to the requirements of a process. Likewise, all forms make it possible to preserve the same overall heat exchange relationship among the fluids passing through the heat exchanger in the different cycles and maintain the same pressure drop through the various passages in each cycle of operation.

What we claim is:

1. A heat exchanger particularly for gaseous media comprising; a cylindrical casing interiorly divided by concentric wall members extending longitudinally thereof to form a pair of adjacent annular passages; partitions extending longitudinally of said exchanger and sub-dividing each annular passage into a pair of contiguous semi-circular sections; multiple fluid inlet ducts each connecting individually with a section of one passage at one side of each partition and with that section of the other passage located at the opposite side of said partition; similarly connected fluid outlet ducts; means forming a channel located adjacent the inner one of said annular passages and concentric therewith; and inlet and outlet ducts connecting with said channel at opposite ends thereof.

2. A heat exchanger particularly for gaseous media comprising; means defining a plurality of independent parallel passages extending from end to end of said heat exchanger parallel to its longitudinal axis; partitions extending parallel to the longitudinal axis of said exchanger and sub-dividing each passage into a pair of adjacent independent sections; multiple fluid inlet ducts each connecting individually with sections of the alternate passages at one side of each partition and with sections of the adjacent passages at the opposite side of each partition; similarly connected fluid outlet ducts; means forming a channel located between two of said passages and parallel therewith; and inlet and outlet ducts connecting with said channel at opposite ends thereof.

3. A heat exchanger particularly for gaseous media comprising; means defining inner and outer pairs of concentric annular passages extending longitudinally of said heat exchanger; partitions extending longitudinally of said exchanger and sub-dividing each annular passage into a plurality of adjacent sections; multiple fluid inlet ducts each connecting individually with sections of the alternate passages at one side of each partition and with sections of the intermediate passages at the opposite side of each partition; similarly connected fluid outlet ducts; means forming a channel located intermediate the inner and outer pairs of passages and concentric therewith; and inlet and outlet ducts connecting with said channel and opposite ends thereof.

4. A heat exchanger particularly for gaseous media comprising; means defining inner and outer pairs of concentric annular passages extending longitudinally of said exchanger; partitions extending longitudinally of said exchanger and sub-dividing each annular passage into a pair of contiguous semi-circular sections; multiple fluid inlet ducts each connecting individually with sections of the alternate passages at one side of each partition and with sections of the intermediate passages at the opposite side of each partition; similarly connected fluid outlet ducts; means forming an annular channel located between the inner and outer pairs of passages and concentric therewith; and inlet and outlet ducts connecting with said channel at opposite ends thereof.

5. A heat exchanger as recited in claim 3 wherein the radial depth of the respective passages and channels is such that they have the same hydraulic diameter.

6. A heat exchanger as recited in claim 3 wherein the concentric circular walls forming said passages and channel are mutually spaced radially of the heat exchanger at distances providing the same hydraulic diameter for all said passages and said channel.

7. A heat exchanger particularly for gaseous media comprising; a cylindrical casing interiorly divided by concentric wall members extending longitudinally thereof to form a pair of adjacent annular passages; partitions extending longitudinally of said exchanger and sub-dividing each annular passage into a pair of contiguous semi-circular sections; an inlet duct for one fluid connecting at one side of one partition with a semi-circular section of one annular passage and at the other side of said partition with a semi-circular section of the adjacent annular passage; an inlet duct for a second fluid connecting with those sections of both said annular passages that are contiguous to the sections connected with said first mentioned inlet duct; similarly connected fluid outlet ducts; means forming a channel located adjacent the inner one of said annular passages and concentric therewith; and inlet and outlet ducts for circulating fluid through said channel in heat exchange relationship simultaneously with said one fluid flowing in a semi-circular section of the adjacent annular passage and with said other fluid flowing in the contiguous semi-circular section of said same annular passage.

8. A heat exchanger particularly for gaseous media comprising; means defining a plurality of independent parallel passages extending from end to end of said heat exchanger parallel to its longitudinal axis; partitions extending parallel to the longitudinal axis of said exchanger and sub-dividing each passage into a pair of adjacent independent sections; an inlet duct for one fluid connecting at one side of one partition with a section of one passage and at the other side of said partition with a section of the adjacent passage; an inlet duct for a second fluid connecting with those sections of both said passages that are contiguous to the sections connected with said first mentioned inlet duct; similarly connected fluid outlet ducts; means forming a channel located adjacent one of said passages and parallel therewith; and inlet and outlet ducts for circulating fluid through said channel in heat exchange relationship simultaneously with said one fluid flowing in a section of the adjacent passage and with said other fluid flowing in the contiguous section of the same passage.

9. A heat exchanger particularly for gaseous media comprising; a cylindrical casing interiorly divided by concentric wall members extending longitudinally thereof to form a pair of adjacent annular passages; partitions extending longitudinally of said exchanger and sub-dividing

each annular passage into a pair of contiguous semi-circular sections; an inlet duct for one fluid connecting at one side of one partition with a semi-circular section of one annular passage and at the other side of said partition with a semi-circular section of the adjacent annular passage; an inlet duct for a second fluid connecting with those sections of both said annular passages that are contiguous to the sections connected with said first mentioned inlet duct; similarly connected fluid outlet ducts; means forming a channel located adjacent the inner one of said annular passages and concentric therewith; and inlet and outlet ducts for circulating fluid through said channel in heat exchange relationship simultaneously with said one fluid flowing in a semi-circular section of the adjacent annular passage and with said other fluid flowing in the contiguous semi-circular section of said same annular passage; and a spiral deflector disposed in said annular channel for causing a volume of fluid flowing through said channel at either side of its longitudinal axis to be transposed about the latter so that as said fluid volume progresses longitudinally of said exchanger it is in heat exchange relationship with the two fluids in the sections of the adjacent passage.

10. A heat exchanger particularly for gaseous media having a passage extending from end to end thereof parallel to its longitudinal axis; transverse partitions in and extending from end to end of said passage and sub-dividing it into a plurality of contiguous sections for flow of fluid in parallel streams longitudinally of said exchanger; an inlet duct for one fluid connecting individually with alternate sections of said passage at one end of said exchanger; an inlet duct for a second fluid connected with the intermediate sections of said passage at the opposite end of said exchanger; similarly connected fluid outlet ducts connected to the other ends of said alternate and intermediate sections; a channel located adjacent said passage and separated therefrom by a common intervening wall; and inlet and outlet ducts connecting with said channel at opposite ends thereof for circulating a third fluid therethrough in heat exchange relationship with the first and second fluids in the sections of said passage.

11. A heat exchanger particularly for gaseous media comprising concentric walls forming an annular passage; transverse partitions in and extending from end to end of said passage and sub-dividing it into a plurality of contiguous sections for flow of fluid longitudinally of said exchanger parallel to its axis; an inlet duct for one fluid connecting individually with alternate sections of said passage at one end of said exchanger; an inlet duct for a second fluid connected with the intermediate sections of said passage at the opposite end of said exchanger; similarly connected fluid outlet ducts connected to the other ends of said alternate and intermediate sections; means forming a channel located adjacent said annular passage and separated therefrom by a common intervening wall; and inlet and outlet ducts connecting with said channel at opposite ends thereof for circulating a third fluid therethrough in heat exchange relationship with the first and second fluids flowing in the sections of said passage.

12. A heat exchanger particularly for gaseous media comprising; a cylindrical casing interiorally divided by concentric wall members extending longitudinally thereof to form a pair of adjacent annular passages; partitions extending longitudinally of said exchanger and subdividing each annular passage into a pair of contiguous semi-circular sections; multiple fluid inlet ducts each connecting individually with a section of one passage at one side of each partition and with that section of the other passage located at the opposite side of said partition; similarly connected fluid outlet ducts; means forming a channel located adjacent the inner one of said annular passages and concentric therewith; inlet and outlet ducts connecting with said channel at opposite ends thereof; and deflecting means disposed across said channel and extending spirally from end to end thereof for directing the fluid in said channel in a stream successively in contact with wall portions thereof in heat exchange relation with fluid flowing through both semi-circular sections of adjacent passages.

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