Dec. 11, 1951 S. HOLM ET AL 2,578,550

MULTIFLUID HEAT EXCHANGER

Filed Jan. 25, 1946 3 Sheets-Sheet 1

Fig. 1

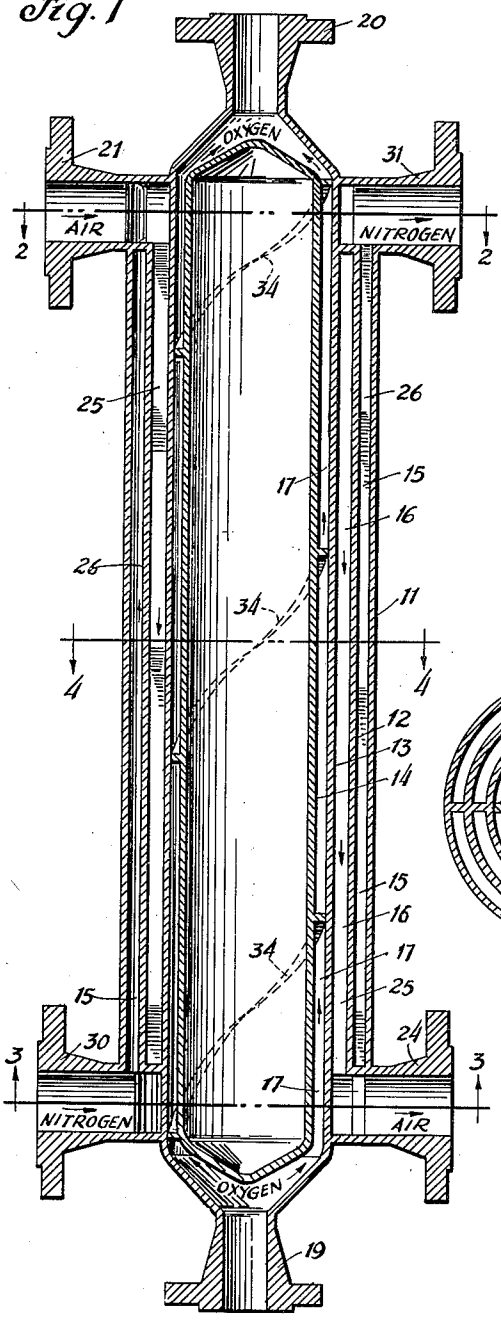


Fig. 2

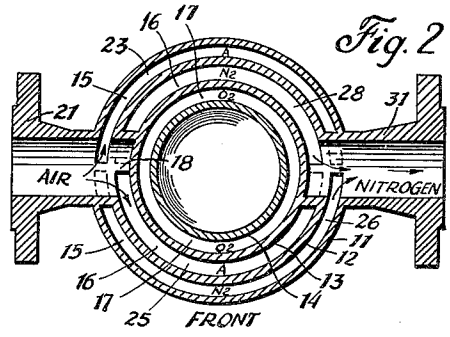


Fig. 3

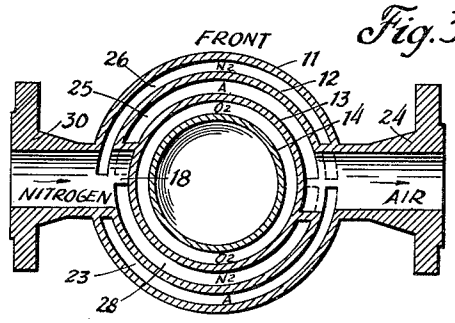


Fig. 4

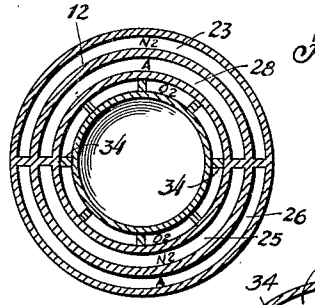
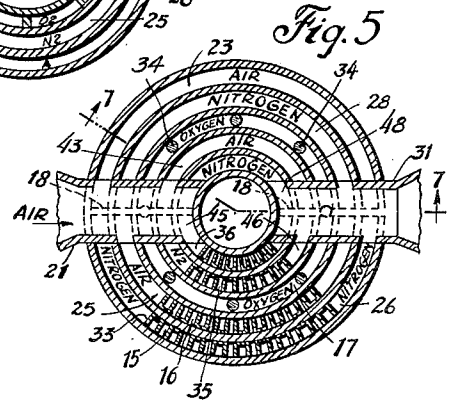


Fig. 5



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Fig. 7

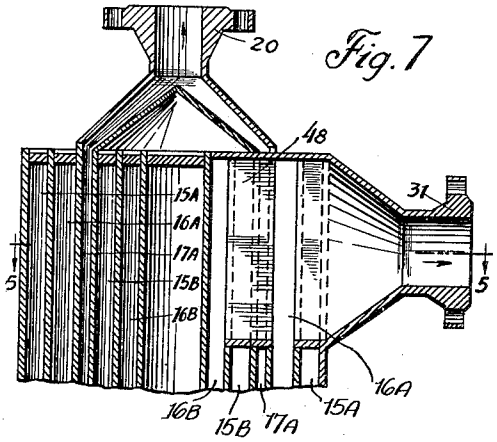


Fig. 8

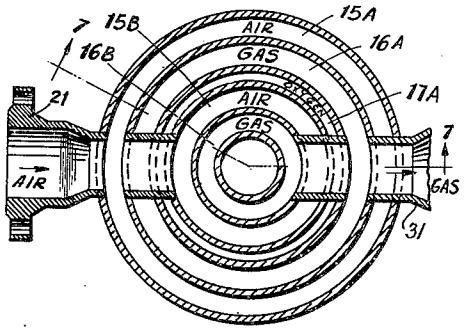


Fig. 10

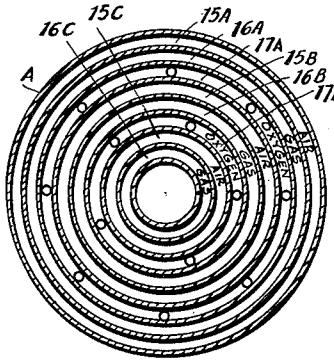


Fig. 11

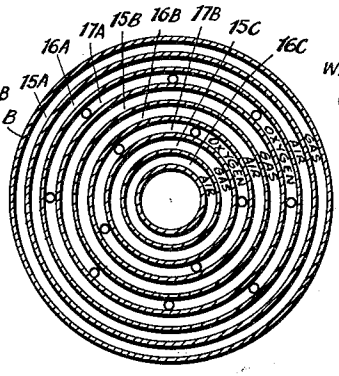


Fig. 6

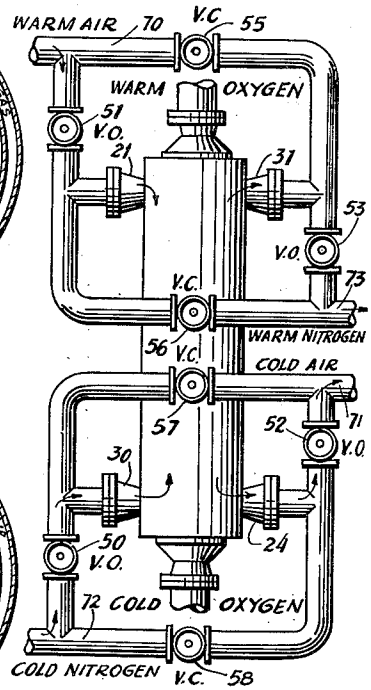


Fig. 12

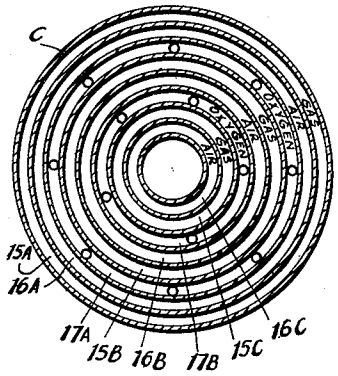
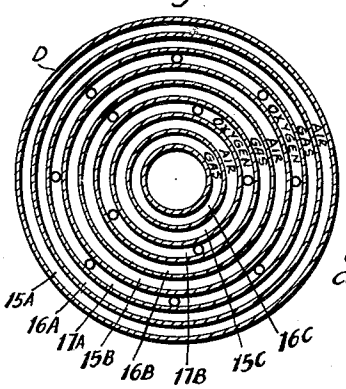


Fig. 13



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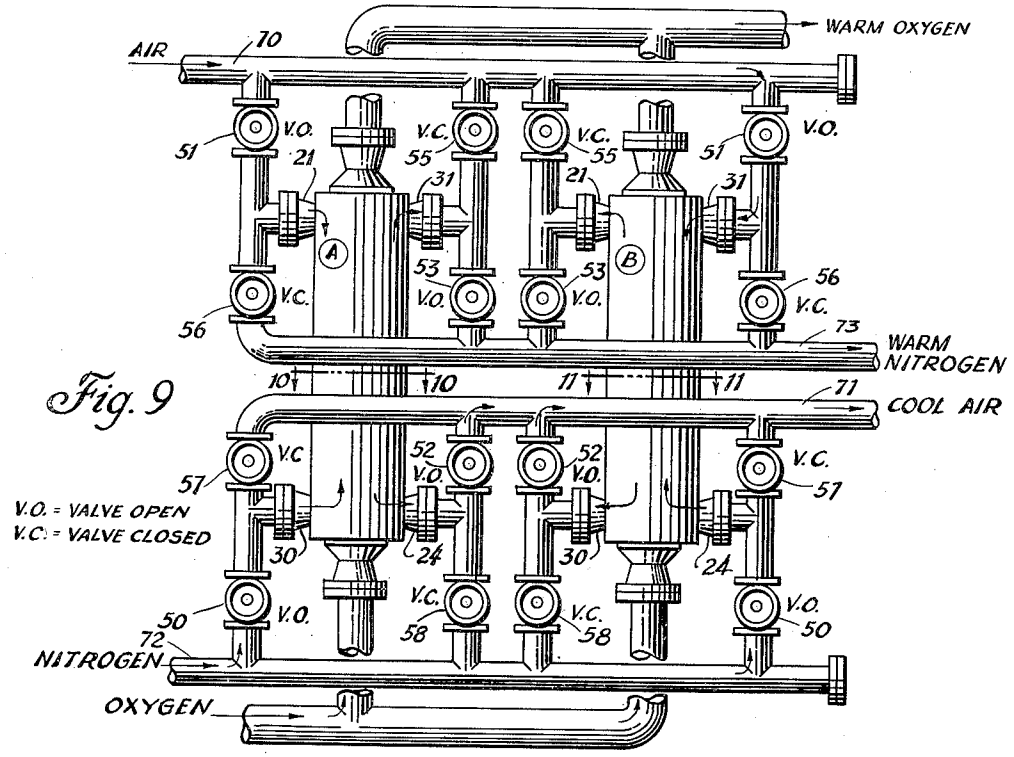


Fig. 9

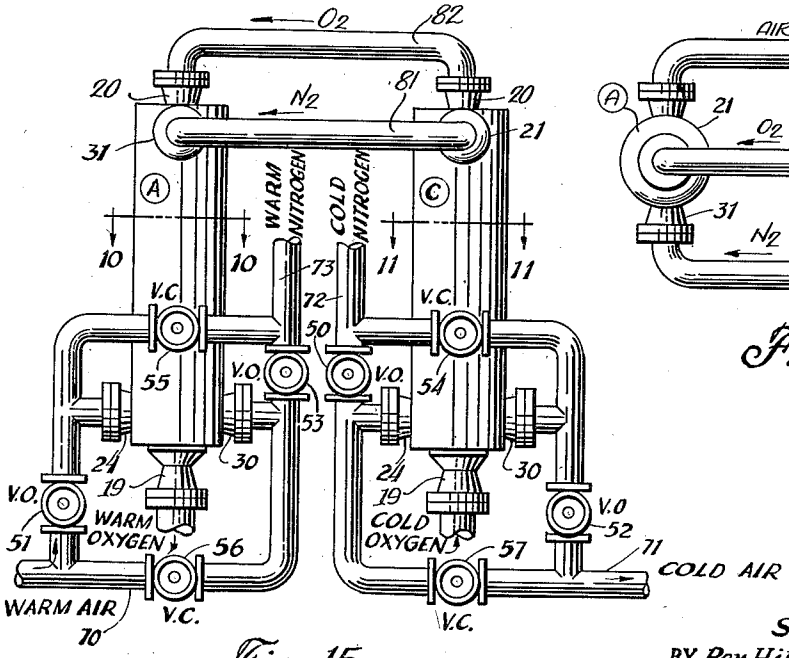


Fig. 15

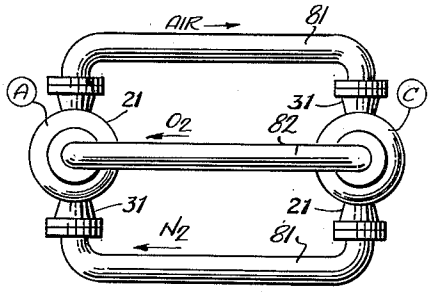


Fig. 14

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MULTIFLUID HEAT EXCHANGER

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Application January 25, 1946, Serial No. 643,331

3 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, illustrating the connections of inlet and outlet ducts with the passages of the exchangers and showing the relations of the fluids in one cycle of operation;

Figure 4 is a sectional view on line 4—4, Fig. 1, illustrating the flow of the fluids during the second cycle of operation of the apparatus shown in Figures 1 to 3.

Figure 5 is a sectional view similar to Figure 2 but showing the connections of inlet and outlet ducts for an exchanger with a larger number of the fluid passages;

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Figure 6 is a diagrammatic view of a heat exchanger embodying the invention and showing its relation to the supply and discharge ducts for the various fluids.

Figure 7 is a fragmentary sectional view of the upper part of a modified form of heat exchanger embodying the invention shown in Figures 1 to 6 but having completely annular passages;

Figure 8 is a sectional view similar to Figures 2 and 5 and illustrates the flow of fluids through the apparatus shown in Fig. 7.

Figure 9 is a diagrammatic view illustrating the connection of a pair of heat exchangers, of the form shown by Figs. 7 and 8, in parallel to the inlet and outlet ducts for the various fluids in practicing the invention;

Figures 10 and 11 are sectional views on corresponding section lines in Fig. 9 and illustrate the flow of fluids through the two heat exchangers.

Figures 14 and 15 are plan and elevational views respectively, illustrating the inter-connection of a pair of the heat exchangers of Figs. 7 and 8 for series flow of fluids therethrough.

Figures 12 and 13 when viewed together with Figs. 10 and 11 illustrate a series-parallel connection of four heat exchangers in accordance with the invention;

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 air to be cooled enters on the left hand side through an inlet connection 21 which communicates at the left hand or upper side (Fig. 2) of the partition 18 with the section 23 of the outermost annular passage 15 and at the right hand or lower side 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, Fig. 3. 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 (Fig. 3) 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, Fig. 2, 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. As described herein, the center space within the wall 14 is not utilized as a heat exchange passage.

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 Figs. 2 and 4 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, the discrepancy in the diameter of the annulae could also result in a difference in pressure drop due to difference in mass velocity. Were nitrogen to flow in the entire intermediate annulus in cycle I (Fig. 1), the oxygen would 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. This is so because 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 Fig. 5 wherein the passages 16 and 36 are of greater radial width than passages 15 and 35 to obtain the same area for flow in the annuli and the same hydraulic diameter of passages between fins. 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 offsetting 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 2 and 4, 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 Fig. 5 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 such that an inlet connection 21 for air 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 the upper and lower halves of Fig. 5. 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. 5 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. 5) 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 but the heat transfer relationships remain the same.

With supply and discharge piping connected as indicated in Fig. 6, all of the valves 50 to 53 are open when air flows through the passage sections 23, 25, Fig. 2 (and also 43, 45, Fig. 5) in the first cycle and nitrogen flows through the sections 26, 28, 46, 48 while all the valves 55 to 58 are closed. Conversely, in the second cycle all of the valves 55 to 58 are open when the nitrogen is to flow through the semi-circular sections 23, 25; (and 43, 45, also in Fig. 5). 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.

As distinguished from the forms of the invention described above the heat exchanger of which details of construction are illustrated in Figs. 7 and 8 has fluid passages which are completely circular or annular in form instead of being sectionally divided into two or more parts as in Figs.

2 and 5. Thus the air which enters through inlet 21 flows both to the right and left, Fig. 8, into the annular passages 15A and 15B while other gas, such as nitrogen, completely fills the annuli 16A and 16B, the oxygen as in previous forms flowing continuously in one direction through the central channel 17A. In order to eliminate conditions of uneven distribution and variation in pressure drop and to maintain the desired heat exchange relationship between the gases while at the same time making it possible to direct the nitrogen through passages through which the air previously flowed and vice versa, two or more units are connected in parallel and two or more parallel groups may be connected in series. The flow of fluids is alternated in each of a pair of units so that in one cycle of operation air flows through certain passages as 15A, B and C, in one unit (Fig. 10) and nitrogen through its passages 16A, B and C while in the second unit (Fig. 11) nitrogen flows through the corresponding passages 15A, B, C, as air flows through the passages 16A, B and C and then upon reversal for the second cycle air and nitrogen each flow through passages transversed previously by the other fluid. As in previous forms the oxygen flows continuously through the passages 17 of both units in each cycle. Thus by utilizing two units each fluid flows through passages of the same mean hydraulic diameter and same cross-sectional area for each cycle.

Thus, as shown diagrammatically, in Fig. 9 air from the supply conduit 70 flows via valve 51 through the inlet 21 into the unit A through annuli 15A, B and C, (Fig. 10) and is discharged from its outlet 24 via valve 52 into the cold air discharge conduit 71. At the same time air enters the unit B via valve 51 and connection 31 and flowing through the annuli 16A, B and C (Fig. 11) is discharged via connection 30 and valve 52 to conduit 71. Simultaneously nitrogen is taken from the supply conduit 72 via valve 50 into the inlet 30 of the unit A and flowing through the passages 16A, B and C (Fig. 10) thereof is discharged through the outlet 31 via valve 53 into the discharge conduit 73 for warm nitrogen. The nitrogen also flows via the connection 24 of the unit B through the passages 15A, B and C (Fig. 11) thereof to pass from the connection 21 via valve 53 into the nitrogen discharge conduit 73. In both units A and B the third gas or oxygen flows continuously through the annuli 17 located between the annuli traversed by air and gas and without change of direction in either cycle. When the valves 50, 51, 52, 53 of both units are closed and the valves 55, 56, 57, 58 of both units are opened, the relationship of the gases is reversed so that nitrogen now flows through the passages 15A, etc. of the unit A while air now flows through the passages 16A, etc. and in the unit B the air now flows through the passages 15A, etc. and the nitrogen through the passages 16A, etc. These relationships are shown in Figs. 12, 13. Thus the reversal of the cycles of operation results not only in purging the passages of ice that may have formed therein from the air but the various gases flow through passages of the same over-all hydraulic diameter in both cycles because if in one cycle the gas flows through an annular passage of large diameter in the unit A, it simultaneously flows through a passage of smaller diameter in the unit B and upon change of cycle the flow is through a small passage in the unit A and through a correspondingly larger passage in the unit B thereby maintaining the same heat transfer and pressure relationships.

Figs. 14 and 15 illustrate the manner of connecting two units for series flow of gases therethrough. The flow of the gases through the passages of the two series connected units A and C and the relation of the gases to each other for one cycle is illustrated in Figs. 10 and 12 respectively. Warm air from the conduit 70 flows through the valve 51 into the unit A (Fig. 10) through the connection 24 and through its passages 15A, B and C to be discharged via connection 21 and pipe 80 to the connection 31 of the unit C (Fig. 12) and through passages 16A, B and C thereof to be discharged through the connection 30 and through the valve 52 into the cold air conduit 71. At the same time nitrogen from supply pipe 72 flows through the valve 50 and via the connection 24 into the unit C through its passages 15A, B and C and out through the connection 21 and pipe 81 into the unit A through the connection 31 flowing through the passages 16A, B and C of this unit and from its connection 30 and valve 53 into the warm nitrogen discharge pipe 73. Oxygen enters the bottom connection 19 of the right hand unit C, flows upwardly through its passages 17A, B and C out through the connection 20 into the pipe 82 into the unit A and down through its passages 17A, B and C and from its outlet 19 into the warm oxygen line. The relationship for the subsequent cycle may be understood by comparing these figures with Figs. 11 and 13. Taken as a whole, Figs 10, 11, 12 and 13 may be considered to illustrate four units with the units A and B connected in parallel and each in turn connected in series with a unit C or D.

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 all 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 heat exchange relationship among the fluids passing through the heat exchanger and maintain the same pressure drop through the various passages in each cycle of operation.

This is a continuation-in-part of United States Patent 2,521,369, issued September 5, 1950.

What we claim is:

1. Heat exchange apparatus particularly for gaseous media, comprising means forming a first group of three concentric passages; means forming another group of three concentric passages similar in size to those of the first group; supply and discharge conduits for a first fluid permanently connected to the inlet and outlet ends of the central passages of the several groups for continuously circulating said first fluid through said central passages; supply and discharge conduits for second and third fluids; piping connecting the supply and discharge conduits for said second and third fluids to the inlet and outlet ends of the outer and inner passages of the three concentric passages in both of said groups; and control valves in said piping located between each inlet and each outlet for said inner and said outer passages of the several groups and both the supply and discharge conduits for said second and third fluids operable to circulate said second fluid through the outer passage of said first group and the inner passage of said other group in heat transfer relationship in both groups with said first

fluid in the central passages thereof while said third fluid flows through the inner passage of said first group and the outer passages of said other group and alternately to circulate said second fluid through the inner passage of said first group and the outer passage in said other group while the third fluid flows through the outer passage of said first group and the inner passage of said other group in continuing heat transfer relationship with said first fluid in the central passages in both groups so that in each cycle of operation the same overall heat transfer relation is maintained between the fluids flowing in said inner and outer passages of the several groups and the fluid flowing in said central passages.

2. Heat exchange apparatus as recited in claim 1 having a plurality of groups of concentric passages, each group comprising at least three passages with the central passages of the respective groups coupled in series flow relation and the outer passage of the three in one group being coupled in series flow relation to the inner passage of the three in a second group, and vice versa.

3. Heat exchange apparatus as recited in claim 1 provided with a plurality of independent passages extending from end to end of the apparatus parallel to its longitudinal axis separated by wall members of heat transfer material; inlet and outlet manifolds so connected as to circulate said first fluid through a first group of passages that are separated from each other by at least one intervening passage; other inlet and outlet manifolds connected to circulate said second fluid through a second group of mutually spaced passages each extending immediately adjacent one of said first group of passages at one side thereof; a third set of inlet and outlet manifolds connected to supply said third fluid to and receive it from opposite ends of a third group of passages each immediately adjacent one of said first group of passages at the other side thereof, the supply and discharge conduits for said first fluid being permanently connected to said first mentioned inlet and outlet manifolds for continuously circulating said first fluid through said passages of said first group and said piping connecting the supply and the discharge conduits for both said second and said third fluids to the inlets and also to the outlet manifolds for said second and third groups of passages.

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PER HILMER KARLSSON.

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