

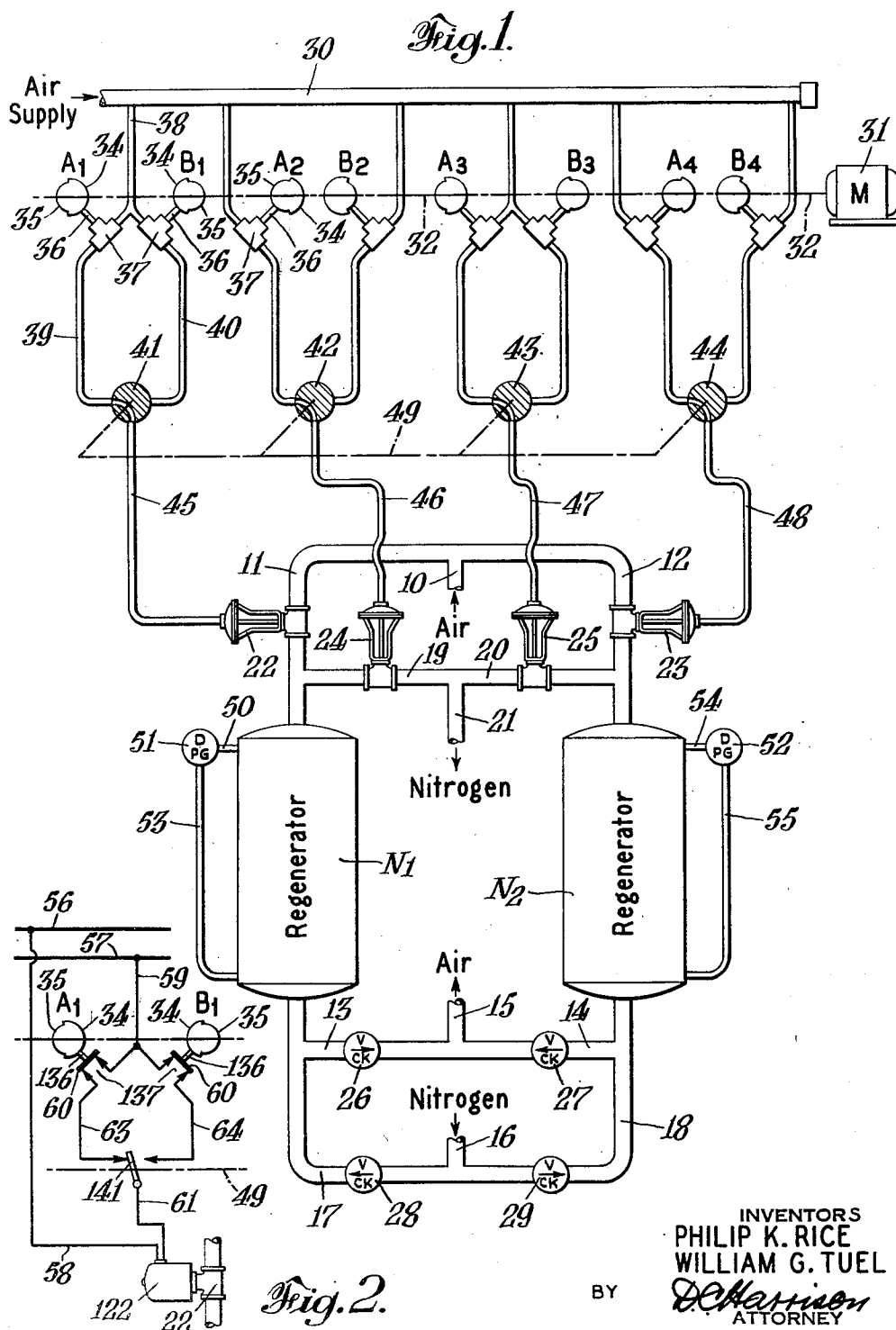
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REVERSED HEAT EXCHANGE DEVICES

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Filed Nov. 10, 1950

2 Sheets-Sheet 1



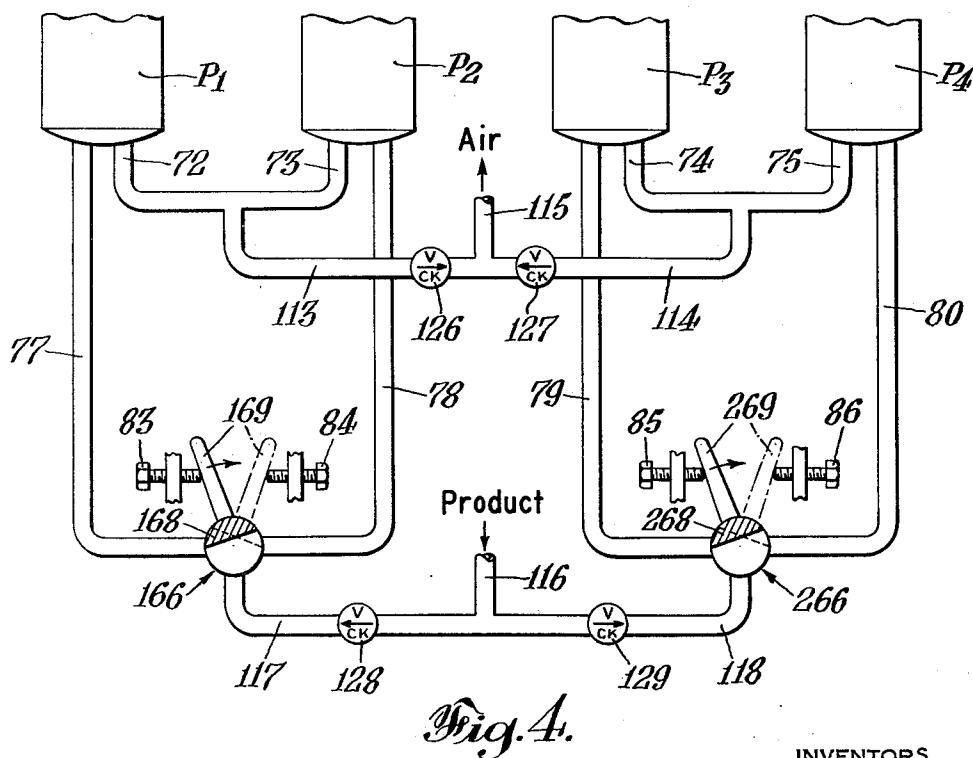
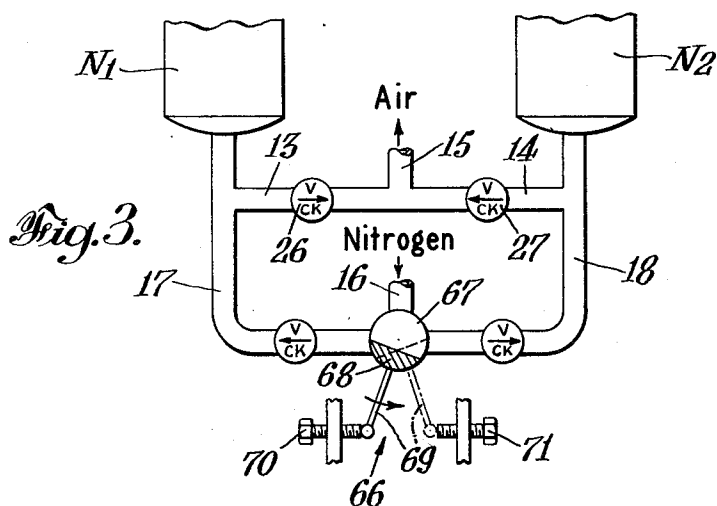
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2,677,252

METHOD AND APPARATUS FOR CONTROLLING PERIODICALLY REVERSED HEAT EXCHANGE DEVICES

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Application November 10, 1950, Serial No. 195,102

15 Claims. (Cl. 62-122)

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This invention relates to a method of and apparatus for controlling the operation of periodically reversed heat exchange devices employed for effecting heat exchange between gaseous fluids, particularly when the gaseous fluid to be cooled contains condensible material.

Heat exchangers of the passage exchanging type and cold accumulators or regenerators are employed for cooling gaseous fluids by the refrigeration gases to be warmed. Such heat exchange devices are particularly useful when the gaseous fluid to be cooled contains condensible material, which condensible material is deposited on the heat exchange surfaces from the gaseous fluid when it passes through one of a pair of such heat exchange passages.

The outflowing gas to be warmed is initially free of such condensible material and is passed outward through the other of the pair of passages. During such outflow, the gas to be warmed effects evaporation of the condensible material that was deposited when that passage was used to cool inflowing gaseous fluid. The volume of the outflowing gas is larger than the volume of the inflowing gaseous fluid which deposits the condensible material. For example, a process for the liquefaction and rectification of air to provide oxygen and nitrogen containing fractions may employ passage exchanging heat exchangers or cold accumulators to effect the heat exchange between the incoming air and the nitrogen and oxygen products leaving the system and since the inflowing air is under pressure, its volume is smaller than the volume of outflowing products.

Water vapor, carbon dioxide, and hydrocarbons are frozen out of the air and deposited on the heat exchange surfaces. The air flows in through one passage or accumulator while the nitrogen, for example, flows outward through the other passage or accumulator. The flows are periodically reversed, so that the nitrogen which flows out through a passage or accumulator through which the air had previously flowed, evaporates the deposited condensible material. The operation of cold accumulators or regenerators is described in United States Patent No. 1,970,299 of M. Frankl.

The reversing passage heat exchanger referred to herein is one in which the air and an outgoing product may flow simultaneously through two passages which are in heat exchanging relation to each other. Such heat exchanger may also have one or more nonreversing passages through which another product or products flow

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constantly. Two sets of the reversing passages are provided, and the flow through such passages is periodically reversed so that for one half-period of the reversing cycle, air will flow inward through one of the passages while outflowing product flows outward through the other of the passages, and during the other half-period of the reversing cycle, the air will flow inward through the other passage while the outflowing product flows through the first-mentioned passage. Such type of heat exchanger is useful when it is desired that the outflowing gas which passes through the nonreversing passage should not be contaminated by impurities and diluted by a residue of the incoming gas to be cooled.

If the flow of the outgoing product through a cold accumulator could be balanced correctly and precisely against the flow of air during the preceding half-period, the deposited materials would be completely removed. In practice it has been found, however, that one of the accumulators may have a slightly higher pressure drop or resistance to flow therethrough than the other of a pair (owing perhaps to a slightly greater packing density), or that operational variations may slightly decrease the flow of nitrogen through one of the accumulators of a pair so that insufficient nitrogen may be available to remove completely the deposited material, particularly the carbon dioxide deposits which are more difficult to remove due to the lower vapor pressure of carbon dioxide in the colder regions of the accumulator. Then in the succeeding air flow period additional deposits of condensible material are made and the pressure drop that creates resistance to nitrogen flow becomes slightly further increased so that even less of the carbon dioxide is removed. Even with perfectly balanced flows such cumulative action once started may cause one regenerator of a pair to become plugged, and it is necessary to completely shut down operation to thaw out the plugged regenerator. This plugging of the regenerators may occur even though the reversing periods are carefully adjusted to be equal and the resistance to gas flow to and from the regenerator passages are adjusted and balanced.

It has been proposed to provide spare full-size regenerators so that when one regenerator of a group becomes clogged, the clogged regenerator would be removed from service and thawed while the spare regenerator would be substituted to continue operation. Such solution is quite uneconomical.

A principal object of the present invention is

therefore to provide an improved method of and apparatus for controlling the operation of periodically reversed heat exchange devices employed for effecting heat exchange between gaseous fluids. More specifically it is an object of the present invention to provide a method of and apparatus for preventing excess accumulation of condensible material in periodically reversed heat exchange devices such as cold accumulators, regenerators, or passage exchanging heat exchangers employed for cooling the gaseous fluid containing such material by a cold gas that is initially free of such material. A further object is to provide a method of and apparatus for controlling the operation of cold accumulators or regenerators used for cooling atmospheric air by the refrigeration of outflowing products of the low temperature separation of air so as to prevent gradual clogging of one or the other of a pair of regenerators by incompletely vaporized carbon dioxide.

These and other objects and advantages of the invention will become apparent from the following description and the accompanying drawings, in which:

Fig. 1 is a diagrammatic view of an exemplary apparatus for controlling the operation of a pair of cold accumulators or regenerators according to the invention;

Fig. 2 is a fragmentary diagrammatic view of a portion of the controlling apparatus employing electrically-operated valves instead of pressure-operated valves;

Fig. 3 is a diagrammatic view of apparatus at the cold end of regenerators for controlling flow according to the invention; and

Fig. 4 is a diagrammatic view of apparatus for controlling flow to a set of four regenerators according to a further aspect of the invention.

It has now been found that the problem of clogging of heat exchanger passages can be solved by operating the heat exchange system in a manner which deliberately unbalances the periodic cycle of air and outgoing product flow. This unbalance is effected so as to pass an excess of one gas through one heat exchange passage of a pair over that passed through the other of such pair until a tendency to clog is indicated and then effecting an opposite unbalance to clear the clogging passage. A preferred way of effecting such unbalance according to the invention makes the period of the reversing cycle for air flow unequal to the period for flow of outflowing separation product. Thus, according to the invention, the reversal period is controlled so that for an indefinite period of operation the time periods for flow of air are greater than the time periods for flow of product for one of a pair of accumulators, the converse being true of the other accumulator. Such unbalanced operation is continued until measurements of pressure drop indicate that condensible material is tending to build up in the one accumulator. Then the operation is deliberately unbalanced in the opposite sense to cause the flow of more air and less product alternatively through the other of the pair of accumulators, which will then reduce or clear out the accumulation of condensible material in the one accumulator. When condensible material tends to clog said other accumulator the operation is unbalanced in the initial direction.

For example, in air separation, wherein air is cooled against outflowing nitrogen product by a pair of regenerators N-1 and N-2, we may assume that regenerator N-1 is indicating an increasing

pressure drop due to carbon dioxide accumulation. If we assume that the complete reversing cycle period is five minutes, the normal or customary time for nitrogen flow through regenerator N-1 or N-2 would be two minutes and thirty seconds, while the normal time for air flow through regenerator N-2 or N-1 would also be two minutes and thirty seconds. According to the invention, the nitrogen flow through regenerator N-1 is increased slightly by from 2 to 10 seconds, for example, to two minutes, thirty-five seconds, while the air flow period through regenerator N-1 is decreased to two minutes, twenty-five seconds. The excess of nitrogen which then passes through regenerator N-1 during the nitrogen flow periods will remove the accumulated deposits. Such unbalanced operation, however, causes the nitrogen flow period for regenerator N-2 to be only two minutes, twenty-five seconds, while the air flow time through regenerator N-2 is two minutes and thirty-five seconds. Eventually such operation, after a number of reversals, causes accumulated deposits to increase in regenerator N-2. Then the reversing cycle is unbalanced in the opposite direction so that the nitrogen flow through regenerator N-2 is increased to two minutes, thirty-five seconds while the air flow through regenerator N-2 is shortened to two minutes, twenty-five seconds. Operation continues in this manner until regenerator N-1 indicates an increasing pressure drop, whereupon the unbalance is again reversed.

The two regenerators of a pair are thus deliberately operated in a manner alternately causing deposits in the one and excess clearing of deposits in the other. Theoretically a regenerator system should not clog if the outgoing product and air flows are in perfect balance. In practice this ideal is not attained, since the regenerators of a pair might not have identical characteristics, and even if they were identical, operational variations can cause them to become unbalanced. Furthermore, deposits of solid material can create greater flow resistance in one regenerator than in the other to initiate a cumulative clogging effect. It is contemplated that this deliberate unbalancing in the correct direction when required may be effected by manual or by automatic response to pressure drop measurements.

Alternatively it is contemplated that the deliberate unbalance may be effected while keeping the reversal period times constant and either increasing the resistance to flow of the air, for example, into regenerator N-1 over that into regenerator N-2, or increasing flow resistance to entrance of outgoing nitrogen to regenerator N-2 over that to regenerator N-1, such unbalance being maintained until regenerator N-2 begins to clog; then deliberately unbalancing the flows by restriction oppositely for a succeeding period of operation. If the total reversal period is short such operation will not affect the pressures seriously because there will usually be adequate volume in the piping or the requisite surge chamber volume may be provided.

Usually the air is compressed by compressor devices such as a rotary compressor, the output volume of which is affected by the head pressure, and therefore, the increased flow resistance when applied to the incoming air, reduces the flow volume. With a constant volume compressor, a surge chamber of suitable volume according to the one-half reversing period time employed could be provided.

The method according to the invention thus

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broadly consists in causing the flow of more of a gaseous fluid and less of a cold gas alternately through one of a heat exchange passage pair than through the other of said pair until condensible material tends to clog the one passage, then causing the flow of more of the gaseous fluid and less of the cold gas alternately through the other of said passages to reduce the accumulation of condensible material in the one passage, and when condensible material tends to clog said other passage, repeating the first step.

Referring now to the drawings, and particularly to Fig. 1, the invention is illustrated by an embodiment of apparatus adapted to control the reversible operation of a pair of regenerators N-1 and N-2 used to cool and condition air by an out-flowing product of air separation, such as the nitrogen product by alteration of the flow time periods.

Air under a relatively low pressure, for example, 75 p. s. i., is supplied through a conduit 10 to branches 11 and 12 which connect conduit 10 to the warm end of the regenerators N-1 and N-2. The cooled air alternately leaves the cold end of the regenerators through conduits 13 and 14 which join an air delivery conduit 15. The nitrogen product is supplied through a conduit 16 connected to branches 17 and 18 that conduct the nitrogen to the cold ends of the regenerators N-1 and N-2. The warmed nitrogen flows from the regenerators through branch conduits 19 and 20 that connect to a discharge conduit 21. The conduits associated with the warm ends of the regenerators are controlled by reversing valves which preferably are stop valves that are motor operated, for example, by fluid pressure or by electrically responsive means. Thus conduit 11 has therein a fluid pressure operated stop valve 22. The branch conduit 12 is controlled by a similar reversing valve 23, while the branches 19 and 20 for nitrogen are controlled by reversing valves 24 and 25. The connections associated with the cold end of the regenerators are preferably supplied with automatically operated nonreturn valves or check valves indicated at 26, 27, 28, and 29 interposed in the respective branches 13, 14, 17, and 18. The check valves 26 and 27 are arranged to permit outflow only of air from regenerator N-1 or N-2 while the check valves 28 and 29 are arranged to permit inflow only of nitrogen to the regenerators N-1 or N-2.

The motor elements of the reversing valves are supplied with timed pressure impulses obtained from a source of fluid pressure which, for example, may be a compressed air supply provided through a manifold conduit 30. To this end there is provided a constant speed motor device 31 which may be a synchronous motor-driven speed reducer constructed to turn a cam shaft, indicated by broken center line 32, at a desired speed providing a complete revolution for each complete reversing cycle period. For example, the cam shaft may make one turn in five minutes. The cam shaft 32 carries a series of cams A-1, B-1, A-2, B-2, A-3, B-3, A-4, and B-4. The cams are provided with high and low cam surfaces 34 and 35 against which cam followers 36 engage. The cam followers are operatively connected to stop valves 37 of which there is one for each cam. The stop valves 37 are connected by conduits 38 to the air pressure line 30, and the outlets of the stop valves 37 are connected by conduits 39 and 40 to two-way valves, there being a two-way valve 41 to receive the pressure impulse from one

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or the other of the stop valves associated with cams A-1 and B-1, a two-way valve 42 connected to receive the pressure impulses from the valves operated by cams A-2 and B-2, a two-way valve 43 connected to receive pressure impulses from valves operated by cams A-3 and B-3, and a two-way valve 44 connected to receive pressure impulses from stop valves operated by cams A-4 and B-4. The two-way valve 41 has its common outlet connected to a conduit 45 connected to deliver the pressure impulse to the reversing valve 22. Similarly two-way valves 42, 43, and 44 have their common outlets connected by conduits 46, 47, and 48 to deliver pressure impulses to the reversing valves 24, 25, and 23 respectively. The two-way valves 41, 42, 43, and 44 may have their operating handles connected together for simultaneous operation, as indicated by the broken line 49.

It will be noted that in one position of the valves 41 to 44 inclusive the reversing valves of the regenerators are connected for operation to those valves 37 which are controlled by the cams A-1 to A-4 inclusive, and when the valve-operating means 49 is shifted to the right, the valves 41 to 44 inclusive will connect the regenerator reversing valves with those valves 37 which are controlled by the cams B-1 to B-4 inclusive. While all of the cams rotate at the same speed, the length of high cam surface 34 of half of the cams is longer than the length of the high cam surface 34 of the rest of the cams. Thus to operate the reversing valves on the cycle timing mentioned hereinabove as an example, all the cams will make one revolution every five minutes and, with respect to the cams A, the length of the high part 34 of cam A-1 will be equivalent to 155 seconds, so as to keep the air flowing into regenerator N-1 for 155 seconds of the time cycle. The cam A-2 should then have a length of high surface 34 equivalent to 145 seconds, so that the time of nitrogen flow will be 145 seconds. It should be noted, however, that the relation of the valve 37 with respect to the cam A-1 and the relation of the valve 37 with respect to the cam A-2 is such that the valve follower 36 for cam A-2 rides on the low side 35 of the cam, while the follower 36 for the cam A-1 rides on the high side 34 of that cam, and vice versa. Therefore reversing valves 22 and 24 can never be simultaneously opened. For the cams A-3 and A-4, the high side 34 of cam A-3 will be similar to cam A-1, providing an opening time of 155 seconds for nitrogen, while the high side of cam A-4 will be similar to cam A-2 and provide an opening time of 145 seconds, so that for regenerator N-2 the time of nitrogen flow is 155 second and for air flow is 145 seconds, and the cam relation is such that when the air is on for regenerator N-1, the air is off for regenerator N-2.

The cams B are arranged so that the high side 34 of cam B-1 is equivalent in length to 145 seconds to provide an air flow time of 145 seconds for regenerator N-1 while the cam B-2 has a length of high side 34 equivalent to 155 seconds to provide 155 seconds of nitrogen flow. Cam B-3 has a length of high surface 34 equivalent to 145 seconds to provide 145 seconds of nitrogen flow for regenerator N-2, while the cam B-4 has a length of high surface 34 of 155 seconds to provide an air flow to regenerator N-2 of 155 seconds. Cams B are also arranged so that for either regenerator, air flow is off when nitrogen flow is on, and vice versa, and also so that when

air flow is on for one regenerator, it is off for the other regenerator.

A convenient way to determine when a regenerator is tending to become clogged is to measure the pressure drop through the regenerator. Such pressure drop measurement can be taken during the period of air flow or during the period of nitrogen flow, and since the nitrogen pressure is lower, it may be preferable to take the measurement during the nitrogen flow period. To this end there may be provided differential pressure gauges 51 and 52, the gauge 51 being connected by conduits 50 and 53 with the ends of regenerator N-1, and the gauge 52 being connected by conduits 54 and 55 with the ends of regenerator N-2.

In operation, the pressure readings of the gauges 51 and 52 for the respective nitrogen flow periods are read and compared, and when it is seen that the pressure drop through regenerator N-1, for example, is consistently becoming greater than the pressure drop through regenerator N-2, the valves 41 to 44 inclusive would be shifted to the right to place the reversing valves 22, 24, 25, and 23 under the control of the cams B. This will cause the air-on time for regenerator N-1 to be 145 seconds, and the nitrogen flow time for regenerator N-1 to be 155 seconds, while the air-on time for regenerator N-2 is 155 seconds, and the nitrogen-on time for regenerator N-2 is 145 seconds. This setting of the two-way valves is maintained until it is noted that the pressure reading of the gauge 52 indicates higher than the pressure reading of the gauge 51, and then the two-way valves 41 to 44 inclusive will be turned to the position shown in Fig. 1. The air time for regenerator N-2 will then be shortened and the nitrogen time for regenerator N-2 lengthened so that this regenerator will gradually become unclogged.

In Fig. 1 there is illustrated a system for controlling the reversing valves by fluid pressure impulses. Alternatively such control can be electrical, and apparatus for electrical control is indicated diagrammatically and fragmentarily in Fig. 2, only the control for one reversing valve being shown. In Fig. 2 the reversing valve 22 is electrically operated by electrically responsive means 122 which may be a solenoid device or an electric motor device. Electric power is furnished through the lines 56 and 57, line 56 being connected by wire 58 to one terminal of the motor device 122. The other line 57 is connected by a connection 59 to one of the terminals of switches 137, there being one switch 137 associated with each cam A-1 to A-4 and B-1 to B-4 inclusive. The cam followers 136 are operatively connected to switch closing bars 60 of the switches 137.

Instead of the two-way valves 41 to 44 inclusive, there are provided two-way switches 141 to 144 inclusive, which are connected respectively to the other terminal of the motor device 122 of the reversing valves by wire 61. The two switch points of switches 141 to 144 inclusive are connected by wires 63 and 64 respectively to the switch 137 of the cams A and the switch 137 of the cams B. It will be seen that when the cam follower 136 contacts the high side of the cam A-1 the switch 137 associated therewith will be closed by the switch bar 60 engaging the switch points. If the two-way switch 141 contacts the switch point to which wire 63 is connected, current will flow through the circuit from line 57, connection 59, switch bar 60, wire 63, switch 141, 75

and wire 61 to the motor device 122, and then through wire 58 to the line 56. In such position of the switches 141 to 144 inclusive, the reversing valves will be in control of the cams A. To place the reversing valves in control of the cams B, the switches 141 to 144 inclusive will be thrown to the right, so that when the cam follower 136 rides on the high side of the cam B-1, current will flow from the line 57 through connection 59, switch bar 60 of the switch associated with cam B-1, wire 64, switch 141, wire 61, to motor device 122, and from thence through wire 58 to line 56.

If desired, the shifting of the two-way valves 41 to 44 or of the switches 141 to 144 could be accomplished automatically by providing a suitable motor device which would be operable in response to the direction of pressure difference between the pressures indicated by the differential gauges 51 and 52. It has been found, however, that the switching of control to one set of cams or to the other set of cams need be done only at relatively long periods, so that manual observation and control will ordinarily be convenient and satisfactory. For example, a set of regenerators with the reversing periods controlled according to the invention was operated with control according to the timing provided by the cams B. Thus the flow of nitrogen through regenerator N-1 is longer, and the flow of incoming air through regenerator N-2 is longer, and regenerator N-1 would tend to become cleared of any carbon dioxide accumulation. From one-thirty to two o'clock, regenerator N-1 showed a slightly higher pressure drop than regenerator N-2. At about two-thirty o'clock, regenerator N-2 began showing a pressure drop greater than that through regenerator N-1. At this time control was switched to the cams A. At about three-thirty both regenerators were operating at the same pressure drop. At four-thirty, regenerator N-1 began to have a slightly higher pressure drop than regenerator N-2, and control was switched to cams B. At about six-thirty the pressure drop through both regenerators was equal, which condition continued until about nine o'clock, when control was shifted back to cams A. Thus it is seen that only a few operations are required during a twelve-hour period and that the length of time for operation under control of one set of cams is not necessarily the same as the length of time under control of the other set of cams.

With the method of operation according to the invention, the regenerators have been in operation for indefinite periods of time without any difficulty due to clogging. It has also been found that clogging of one or the other of a pair of regenerators tended to occur irrespective of other means employed for unbalancing the regenerators, such as a bleeding off from an intermediate portion of the regenerators or a portion of the air before such portion has deposited its carbon dioxide, and the provision of the outflowing gas at such a temperature that the carbon dioxide deposited in the coldest part of the regenerator will have sufficient vapor pressure so that it may be revaporized.

The above-described control of the flow time periods of the reversing cycle may be also employed for the operation of a second set of regenerators employed to cool incoming air by a gaseous oxygen product in a plant that produces gaseous oxygen as well as effluent nitrogen. In some large plants the regenerators for cooling air by one of the products comprise more than

two, for example four, six, or eight regenerators comprise a set. In such cases one-half the regenerators of a set will be controlled and operated in parallel similarly to regenerator N-1 and the other half of the regenerators will be operated in parallel similarly to regenerator N-2. One-half the parallel operating regenerators may be controlled by a common reversing valve 22 or 23 for air and a common reversing valve 24 or 25 for outgoing product and the unbalancing of the flow time periods may be effected as described above in connection with regenerators N-1 and N-2. Smaller reversing valves can be employed by using individual reversing valves for each parallel operating regenerator and then the timing control system will be similar as to cams and two-way valves 41 to 44 of Fig. 1 but differ only in providing branches of the pressure impulse lines 45 to 48 sufficient to simultaneously control the individual reversing valves of each group of parallel operating regenerators.

For carrying out the method of deliberate unbalance by keeping the half-periods of the reversing cycle constantly equal and effecting deliberate flow restrictions, the customary reversing valve mechanism providing equal times may be employed and there may be added suitable flow restricting means such as partial shut-off valves in the pipes conducting air into or out of each regenerator or in the pipes conducting the cold product into or out of each regenerator. An example of such a control is illustrated in Fig. 3 as applied to outgoing nitrogen. Only the lower ends of regenerators N-1 and N-2 are shown as the control mechanism of the upper ends is the customary type providing equal half-periods of flow for air and nitrogen. The piping at the lower or cold ends is similar to that at the lower part of Fig. 1, but at the junction of conduits 16, 17, and 18 there is diagrammatically illustrated a two-way restriction device 66. This may be similar to a two-way plug valve having a rotor 67 that never cuts off the opening to conduit 16 but has a flow-restricting segment 68 opposite conduit 16. The rotor is turnable by a laterally extending operator handle 69 through a limited arc as determined by adjustable limit stops 70 and 71 that are positioned to engage the handle 69 when it is in either extreme position. When the handle 69 contacts stop 71 the segment 68 partially restricts the passage between conduits 16 and 17 while allowing free passage between conduits 16 and 18. When the handle 69 contacts stop 70 the segments 68 partially restricts flow between conduits 16 and 18 and allows free flow between conduits 16 and 17.

With the device 66 positioned as shown in Fig. 3, regenerator N-1 will receive less outflowing nitrogen during its nitrogen flow half-periods than regenerator N-2 and, since the air flows are substantially equal, regenerator N-2 will positively clear itself of deposits while regenerator N-1 will tend to clog. When such clogging is definitely indicated by pressure drop measurements, the device 66 is shifted to the opposite position to effect clearing of regenerator N-1 with eventual clogging of regenerator N-2.

It will be seen that a slight back pressure may build up only during the half-period of nitrogen flow through that regenerator through which the flow is restricted. Such back pressure surge is dissipated during the succeeding half-period of the reversing cycle and causes more nitrogen to flow through the regenerator that is not deliberately restricted. The back pressure build-up or

surge is minimized by the volume of piping and passages including conduit 16 and if desired such volume can be increased by providing an enlargement or surge chamber in or connected to the conduit 16. The degree of flow restriction to be effected should be just definitely more by a small amount than the maximum restriction due to clogging by deposited material which can clearly be observed by pressure drop observations.

Alternatively, as mentioned hereinabove, a similar flow restriction device may be employed to control the air supply conduits, and if the air is supplied by a rotary compressor the volumetric output of which is affected slightly by the back pressure, no surge chamber may be needed.

A similar control by restriction of flows may be applied to the heat exchanger set for gaseous oxygen product in plants producing gaseous oxygen. In such case it will be preferable to arrange the reversal cycles of the nitrogen passage pair and the oxygen passage pair so that when the air for the nitrogen pair is on the restricted half-period, the air for the oxygen pair is on the unrestricted half-period to minimize back pressure surge effects.

When two or more parallel operating regenerators form one-half of the regenerators of a set for warming an outgoing product, the method of unbalance by flow restrictions can also be employed. This is illustrated in Fig. 4 as applied to the outgoing product warmed in a set of four regenerators P-1, P-2, P-3, and P-4. These have piping and reversing valves at their warm ends providing equal half-periods of reversing cycle and so that air flows in through regenerators P-1 and P-2 while product gas flows out through regenerators P-3 and P-4 during one half-period and during the other half-period the flows are reversed.

At the cold ends shown in Fig. 4, the air outlet connections are conventional except that connection 113 has branches 72 and 73 connecting to regenerators P-1 and P-2 and connection 114 has branches 74 and 75 connecting to regenerators P-3 and P-4. During one half-period air passes out through branches 72 and 73, connection 113, check valve 126 to cold air outlet conduit 115, and during the other half-period air passes out through branches 74 and 75, connection 114, check valve 127, to conduit 115.

The outgoing product supplied at conduit 116 flows as permitted by the reversing valves at the warm ends either through check valve 128 and connection 117 to the inlet of a two-way restriction device 166 or through check valve 129 and connection 118 to a two-way restriction device 266. These devices may be similar to that shown at 66 in Fig. 3 having rotor segments 168 and 268 movable by operator arms 169 and 269 to either of two extreme positions, one such position being illustrated in Fig. 4. The side outlets of the devices 166 and 266 are connected by conduits 77 and 78 respectively to the regenerators P-1 and P-2 and by conduits 79 and 80 to the regenerators P-3 and P-4. Limit stops may also be provided, for example, adjustable stops 82 and 84, 85 and 86 may limit the movement of the arms 169 and 269 respectively to provide the desired amount of flow restriction through the devices 166 and 266 from connections 117 and 118 to conduits 77 and 79 respectively in the positions shown in Fig. 4 and when the arms 169 and 269 are moved to the other limits 84 and 86, to provide the desired flow restriction from

connections 117 and 118 to conduits 70 and 80 respectively.

In a preferred method of operation of a duplicate set of regenerators, the flow of air to the regenerators P-1 and P-2 at the warm ends will be balanced as closely as possible to the flow of air to regenerators P-3 and P-4 by the addition of a slight flow restriction as required to make the total flow resistance the same on either setting of the reversing valves when the regenerators are clean.

With the positions shown in Fig. 4, and during the half-periods when product flows through regenerators P-1 and P-2, the regenerator P-2 will receive more outflowing product than regenerator P-1 so that regenerator P-1 will have a tendency to clog. Also regenerator P-4 receives more outflowing product than regenerator P-3 during the remaining half-periods, so that regenerator P-3 will have the tendency to clog while regenerators P-2 and P-4 will tend to become cleared of any accumulated deposits. When, after operating as shown in Fig. 4 for an indefinite time, regenerator P-1 or P-3 may indicate clogging, then the device 166 or device 266 is switched. If device 166 is switched, regenerator P-1 will become positively cleared while regenerator P-2 will then tend to clog. If at a different time regenerator P-3 shows excessive pressure drop, device 266 is switched, causing regenerator P-3 to become positively cleared, while regenerator P-4 will tend to clog.

A similar flow-restricting control may be used alternatively in the air conduits when multiple regenerators are employed and the benefits will be similar. Instead of controlling by flow resistance unbalance, a set of multiple regenerators may be controlled by the method of unequal flow periods. With equal time periods, the reversing valves for outgoing product, for example flowing from regenerators P-1 and P-2, would be open simultaneously for the outgoing product half-period, but to deliberately restrict flow through regenerator P-1 and favor P-2, the reversing valve for regenerator P-1 may be controlled to open a little later and close a little earlier than the reversing valve for regenerator P-2. When regenerator P-1 indicates clogging, the timing of the two reversing valves may be switched. A similar timing control may be applied to the reversing valves of regenerators P-3 and P-4.

What is claimed is:

1. A method of preventing excess accumulation of condensible material in periodically reversed heat exchange devices employed for cooling an initially warm gas containing such condensible material by a cold gas which is initially free of the condensible material including condensation of material from the initially warm gas and evaporation of material into the initially cold gas, the periodic reversal being effected by a succession of complete reversal cycles each consisting of two periods during the first of which the initially warm gas flows from the warm end to the cold end of one of a heat exchange passage pair while the initially cold gas flows from the cold to the warm end of the other of the heat exchange passage pair and during the second period of the cycle the initially warm gas flows from the warm to the cold end of the other of said pair while the initially cold gas flows from the cold to the warm end of the first mentioned one of said pair, which method comprises causing during each complete reversal cycle of a succession

of cycles the flow of one of said gases through one of the heat exchange passage pair to be more by a predetermined amount than through the other of said pair until a residue of condensible material tends to clog one of said pair; then causing the flow of said one gas through the other of said pair to be more by a predetermined amount than through said first-mentioned one of said pair to reduce said accumulation of condensible material in the partly clogged passage; and when condensible material tends to clog the originally unclogged passage, repeating the first step.

2. A method of preventing excess accumulation of condensible material in periodically reversed heat exchange devices according to claim 1, in which the unbalance of flow is effected by maintaining the periodic reversal times of the two periods of each complete reversing cycle substantially equal and causing the increased flow through one of the passage pair by imposing additional resistance to flow through the other of said pair.

3. A method of preventing excess accumulation of condensible material in periodically reversed heat exchange devices according to claim 1, in which the unbalance of flow is effected by making the flow times of the two periods of each complete reversing cycle unequal, such that the time of flow of one of said gases through one of said passage pair is longer than the time of flow of said one gas through the other of said pair.

4. A method of preventing excess accumulation of condensible material in periodically reversed heat exchange devices employed for cooling gaseous fluids containing such condensible material by cold gas which is initially free of the condensible material, which method comprises decreasing by a predetermined amount the periodic time of flow of the cold gas through one of a heat exchange passage pair while correspondingly increasing the periodic time of flow of the cold gas through the other of said pair until condensible material tends to clog said one; then switching such timing inequality to provide the shorter periodic time of flow of the cold gas through the other of said pair than through said one to reduce the accumulation of condensible material in said one passage; and when condensible material tends to clog said other passage, repeating the first step.

5. A method of preventing excess accumulation of condensible material in periodically reversed heat exchange devices employed for cooling gaseous fluids containing such condensible material by cold gas which is initially free of the condensible material, which method comprises increasing by a predetermined amount the periodic time of flow of the gaseous fluid through one of a heat exchange passage pair while correspondingly decreasing the periodic time of flow of the gaseous fluid through the other of said pair until condensible material tends to clog said one; then switching such timing inequality to provide greater periodic time of flow of the gaseous fluid through the other of said pair than through said one to reduce the accumulation of condensible material in said one passage; and when condensible material tends to clog said other passage, repeating the first step.

6. A method of preventing excess accumulation of condensible material in periodically reversed heat exchange devices employed for cooling gaseous fluids containing such condensible material by cold gas which is initially free of

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the condensible material, which method comprises increasing by a predetermined amount the resistance to flow of the cold gas through one of a heat exchange passage pair so that less cold gas flows through same than through the other of said pair until condensible material tends to clog said one; then removing said increased resistance and increasing by a predetermined amount the resistance to flow of the cold gas through the other of said pair so that less cold gas flows through said other than through said one to reduce the accumulation of condensible material in the one passage; and when condensible material tends to clog said other passage, repeating the first step.

7. A method of preventing excess accumulation of condensible material in periodically reversed heat exchange devices employed for cooling gaseous fluids containing such condensible material by cold gas which is initially free of the condensible material, which method comprises increasing by a predetermined amount the resistance flow of the gaseous fluid through one of a heat exchange passage pair so that less gaseous fluid flows through same than through the other of said pair until condensible material tends to clog said other of the pair; then removing said increased resistance and increasing by a predetermined amount the resistance to flow of gaseous fluid through the other of said pair so that less gaseous fluid flows through said other than through said one to reduce the accumulation of condensible material in said other passage; and when condensible material tends to clog said other passage, repeating the first step.

8. Apparatus for controlling the operation of periodically reversed heat exchange devices that cool an initially warm gas containing condensible material by an initially cold gas that is initially free of such material, which apparatus comprises, in combination with gas flow reversing mechanism for periodically reversing the flow of the warm gas and the cold gas through a pair of heat exchange passages; of switching apparatus shiftable to either of two settings and constructed and arranged, when shifted to one of said settings, to effect the flow of a predetermined greater amount of one of said gases through one of such pair of passages than through the other of said pair for a desired number of reversal periods and for a succeeding desired number of reversal periods when shifted to the other of said settings, to effect the flow of a predetermined lesser amount of said one gas through said one passage than through said other passage.

9. Apparatus for controlling the operation of periodically reversed heat exchange devices according to claim 8 in which said reversing mechanism includes reversing valves interposed in the gas connections at the warm ends of the heat exchange passages, said valves having motor operators, and means for delivering timed motive impulses to said motor operators; and said switching apparatus comprises duplicate devices for delivering said timed impulses constructed to deliver oppositely phased longer and shorter impulses, and switching means to switch control of said motor operators to either of the duplicate impulse delivering means.

10. Apparatus for controlling the operation of periodically reversed heat exchange devices according to claim 8 in which said switching apparatus comprises flow resistance increasing devices connected to control the flow of a gas through

each of said heat exchange passages; and operating means for said devices operable for increasing the resistance to flow of said one gas through said other of said pair of passages for said desired number of periods and for eliminating such increased resistance and increasing the resistance to flow of said one gas through said one passage for the succeeding number of reversal periods.

11. Apparatus for controlling the operation of periodically reversed heat exchange devices that cool a warm gas containing condensible material by a cold gas that is initially free of such material, which apparatus comprises, in combination with reversing valves interposed in gas connections at the warm ends of a pair of heat exchange passages and operable to periodically reverse the flow of initially warm gas and initially cold gas through such passages, said valves having motor operators; of means including pairs of cams all connected to be driven at a rate corresponding to the complete reversal cycle, said cams having two cam follower positioning portions of unequal length and the total length of said two portions corresponding to a complete reversing cycle, and the follower positioning portions of the two cams constituting each pair being oppositely related; cam followers for each cam operatively connected to impulse delivering means; and switching means connected between the two impulse delivering means associated with each pair of cams and one of said motor operators and operable to switch control of the motor operator to receive impulses from the impulse delivering means operated by either of the cams of a pair of cams.

12. Apparatus for controlling the operation of periodically reversed heat exchange devices that cool a warm gas containing condensible material by a cold gas that is initially free of such material and including two sets of heat exchange passages and two or more heat exchange passages forming each set and connected together to operate as a unit, which apparatus comprises in combination with means for periodically reversing the flow of the warm gas and the cold gas alternately through each set of heat exchange passages; flow resistance increasing devices connected to control the flow of a gas through each of said heat exchange passages; and operators for said devices operable to apply added flow resistance to half the number of heat exchange passages of a set for a desired number of reversal periods and to remove such resistance and apply added flow resistance to the other half of the heat exchange passages of said set.

13. Apparatus for controlling the operation of periodically reversed heat exchange devices according to claim 12, which includes means for initially balancing the flow of gas among the several heat exchange passages.

14. Apparatus for controlling the operation of periodically reversed heat exchange devices that cool an initially warm gas containing condensible material by an initially cold gas that is initially free of such material, which apparatus comprises, in combination with gas flow reversing mechanism for periodically reversing the flow of the warm gas and the cold gas through a pair of heat exchange passages, said mechanism comprising conduits having automatic valves controlling the flow of the cooled warm gas from and the cold gas to the cold ends of said passages, motor operated valves controlling con-

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duits at the warm ends of said passages to start and stop flow of warm gas alternately to and of initially cold warmed gas alternately from said passages, and mechanism for timing the operation of said motor operated valves to effect successive complete reversal cycles consisting of two periods during a first period of which the motor valve controlling flow of warm gas to one passage is open and the motor valve controlling flow of warm gas to the other passage is closed while the motor valve controlling discharge from the one passage is closed and the motor valve controlling discharge from the other passage is open and during the last period of the reversal cycle the motor valves are oppositely positioned; of switching apparatus associated with said gas flow reversing mechanism and shiftable to either of two settings and constructed and arranged when shifted to either of said settings to unbalance the flow times of said first and last periods of the reversal cycle.

15. Apparatus for controlling the operation of periodically reversed heat exchange devices that cool an initially warm gas containing condensible material by an initially cold gas that is initially free of such material, which apparatus comprises, in combination with gas flow reversing mechanism for periodically reversing the flow of the warm gas and the cold gas through a pair of heat exchange passages, said mechanism comprising conduits having automatic valves controlling the flow of the cooled warm gas from and the cold gas to the cold ends of said passages, motor operated valves controlling con-

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duits at the warm ends of said passages to start and stop flow of warm gas alternately to and of initially cold warmed gas alternately from said passages, and mechanism for timing the operation of said motor operated valves to effect successive complete reversal cycles consisting of two periods during a first period of which the motor valve controlling flow of warm gas to one passage is open and the motor valve controlling flow of warm gas to the other passage is closed while the motor valve controlling discharge from the one passage is closed and the motor valve controlling discharge from the other passage is open and during the last period of the reversal cycle the motor valves are oppositely positioned; of switching apparatus associated with said conduits and shiftable to either of two settings and constructed and arranged when shifted to one of said settings to introduce increased resistance to flow of one of said gases through one of such pair of passages than through the other of such pair for a desired number of reversal cycles and when shifted to the other of said settings to eliminate said increased resistance and introduce increased resistance to flow of said one gas through the other of said pair of passages for a succeeding desired number of reversal cycles.

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