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[54] **METHOD OF AND APPARATUS FOR HEAT EXCHANGE BETWEEN GAS STREAMS**
11 Claims, 2 Drawing Figs.

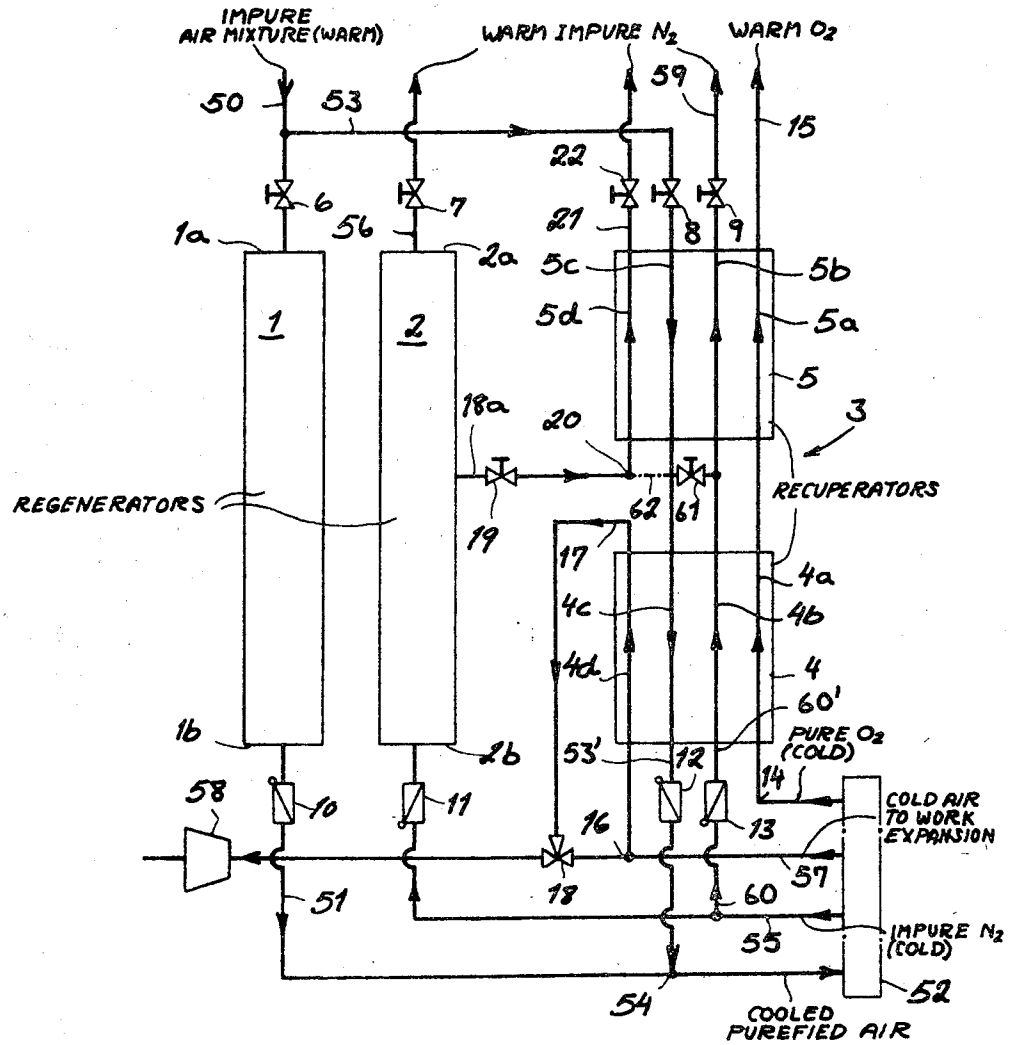
[52] U.S. Cl. 62/13, 62/39
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ABSTRACT: A system for the heat exchange of low-temperatue gas mixtures, e.g. for the separation of gases in an air rectification installation or the like, in which part of the cold is obtained by expansion of a warm fraction of the gas mixture to be rectified or from a portion of the rectification products. The heat exchanger system is subdivided into regenerators and recuperators which are interchangeable in function at least in part. The recuperator system is subdivided into a relatively cold recuperator branch and a relatively warm recuperator branch. A portion of the gas mixture to be expanded or the aforementioned fraction of the rectification product is warmed in an unswitched passage of the colder recuperator branch while another fraction of the gas mixture or rectification products is withdrawn form an intermediate location of the regenerator and is passed through the warmed recuperator branch.



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METHOD OF AND APPARATUS FOR HEAT EXCHANGE BETWEEN GAS STREAMS

My present invention relates to a method of and an apparatus for effective heat exchange between low-temperature or cryogenic fluids and, more particularly, to a system for transferring heat between the several fluids of a gas separation (e.g. air-rectification) installation.

It has already been proposed to carry out a low-temperature gas separation by bringing a gas mixture to be fractionated to a relatively low temperature and, by means of heat exchange and/or liquefaction towers, carry out an efficient separation of one gas from another at or below the boiling points of the several gases. A typical system of this nature is that known as the Linde-Frankl air rectification system and, when reference is made herein to gas separation, air rectification and the like, it will be understood that a Linde-Frankel system or some corresponding system for separating other gases at low temperature is intended (See the commonly owned U.S. Pat. Nos. 3,256,704, 3,364,686, 3,421,332, 3,421,335).

It has been proposed, in connection with air rectification, to provide regenerative heat exchangers or so-called regenerators, to effect heat exchange between the compressed air which must be cooled and the rectification products, prior to separation of the compressed air into its components in the rectification column. This cooling of the nonseparated gas or impure gas mixture not only prepares the mixture for subsequent rectification steps but also precipitates out impurities such as water vapor and carbon dioxide. In this system, the compressed impure gas is passed through the regenerator which has been previously brought to a low temperature by passing therethrough a rectification product, whereupon latent heat of condensation and fusion is absorbed by the impurities in the compressed air from the heat storage mass and condenses, precipitates and solidifies the same in the tube coils of the regenerator. In the subsequent half-cycle of the operation of the regenerator, a rectification product, usually relatively impure nitrogen, is passed through the turns of the regenerator coil to absorb heat therefrom and sweep the precipitated impurities from the heat exchanger, an initial removal of the impurities being effected possibly by the application of suction or reduced pressure to the regenerator so as to cause sublimation of the precipitated impurities. When the low-temperature gas is passed through the coil, it absorbs heat from the heat storage mass of the regenerator and "transfers cold" to the latter.

To cover the cold requirements of low-temperature air separation, compressed air or compressed nitrogen is work expanded, e.g. subjected to expansion in an expansion turbine or like system for converting potential energy of compression to mechanical work, the expansion giving rise to a reduced-temperature gas at a lower pressure. Prior to expansion, the removal of the water vapor and carbon dioxide is necessary and such removal is carried out, as noted above, in tube coils of a regenerator close to the cold end thereof.

The term "regenerator" is used herein to refer to an indirect heat exchanger of the type in which a heat storage mass of high thermal capacity is provided in heat-exchanging relationship with one or more fluid passages and low- and high-temperature gases are passed alternately through these passages in opposite directions to transfer cold to the heat storage mass or abstract heat therefrom, and to absorb heat from the thermal reservoir or transfer cold thereto.

While generally it is convenient to refer to cooling as a removal of heat, and this is the convention widely used in other fields, in low-temperature systems and especially those operating with gases at temperatures close to their boiling point, an essential problem is the maintenance of "cold" and the prevention of cold loss. Cold loss, of course, may be described in terms of heat leakage into the system, but for the present purpose and for the convenience of workers in the field with which the present invention is concerned, reference may be made to conservation of cold, cold loss, cold requirements, the storage of cold and the transfer of cold between fluids.

In place of the purely regenerative heat-exchange systems characterizing low-temperature air rectification since the proposals of Frankl in about 1925, today various heat exchange systems are employed using plate-type heat exchangers in which several compartments are in heat-exchanging relationship with one another through the thermally conductive walls of the heat exchanger. Pairs of the compartments of such heat exchangers may be functionally interchanged or switched so that they are sued in alternate half-cycles for one or another fluid in a manner not unlike the functional interchange discussed above in connection with regenerator systems. Heat exchangers of the type in which heat transfer occurs through a wall separating two fluid compartment through which both fluids are simultaneously fed, will hereinafter be referred to as recuperators.

In the application of such recuperators to modern low-temperature air rectification, one of the switchable compartments of the recuperators may serve for the purification of the compressed air by the condensation or the freezing-out of its high boiling point impurities such as water vapor and carbon dioxide. The heat of condensation and fusion is transferred indirectly through the wall of the compartment to a cooling fluid and is immediately absorbed thereby. In the next half-cycle, an impure gas, for example nitrogen, obtained from the rectification installation and which has previously been passed through another switchable compartment of the recuperator, is shunted to the compartment previously used to purify the air and sweeps the water vapor and carbon dioxide, after volatilization, from this compartment. At the same time, the impure compressed-air stream is switched to the compartment previously abandoned by the impure nitrogen stream. During such recycling, relatively pure gas from the air rectification installation, e.g. pure oxygen, is passed through nonswitchable compartments of the same recuperator and is warmed in heat exchange through the compartment walls with the impure air.

It has also been suggested to make use, in air rectification systems of the aforedescribed type, of a combination of regenerators with recuperators. For heat exchange with the pure products, the recuperators are employed. For example, pure oxygen recovered from the air rectification installation and a portion of the compressed air are passed in indirect heat-exchanging relationship simultaneously through separate compartments of a recuperator to warm the oxygen and chill the compressed air. At the same time, an additional quantity of impure nitrogen is passed in heat exchange with additional compressed air through the recuperator and the high boiling point impurities are flushed by this impure nitrogen stream. These impurities being deposited from the compressed air as a result of its cooling by the pure oxygen. The remainder of the compressed air quantity and the remainder of the impure nitrogen exchange heat in regenerators, i.e. the balance of the compressed air being passed through a previously cool regenerator while the balance of the impure nitrogen is passed in the opposite direction through a warm regenerator in which the high boiling point impurities have been deposited by condensation and solidification in a previous half-cycle. The excellent thermal storage characteristics of the regenerators and the large heat exchange surface area provided therein result in a correspondingly efficient condensation and solidification of the impurities over these large areas. As a result of fluctuations in the amount of these impurities and fluctuations in the amount of impure nitrogen necessary to purge the impurities from the regenerators, difficulties are encountered in the rectification installation since heat imbalance may be result. To counter these variations, it has been proposed, as already noted, to make use of the large storage capacity of the regenerators and carry out the greater part of the heat transfer with the impure compressed air in the regenerators, thereby damping the fluctuations.

It has already been noted that, in the heating of the gas to be expanded in the work expansion stage of the air rectification

installation, the gas is passed through tube coils which are provided in the cold sections of the regenerators. Since the temperature difference between the gas streams for heating and warming is held rather small at the cold end of the regenerator the condensation and precipitation of the impurities (e.g. H_2O and CO_2) from the compressed air occurs practically to completion. The recuperators used to heat the pure gas rectification products are capable of cooling somewhat more compressed air over the total temperature range thereof than the recitification products which in turn are heated. An important disadvantage of these conventional systems, however, is that tube coils which are to be built into the regenerators are highly expensive, are difficult to manufacture and complicate the heat exchange process.

It is, therefore, the principal object of the present invention to provide an improved method of effecting heat exchange between an impure gas mixture and air rectification products derived from the low-temperature rectification of the compressed air, which is more efficient than earlier systems, which can be carried out with greater rationality and which makes use of simpler heat exchange units.

Another object of this invention is to provide a heat exchange system adapted to be used in conjunction with a low-temperature air rectification installation in which the aforementioned disadvantages can be obviated.

These objects and others which will become apparent hereinafter, are attained, in accordance with the present invention, in a system in which the fraction of the compressed gas mixture (i.e. air to be subjected to work expansion, i.e. expansion against a load) or a fraction of the rectification products are passed through nonswitchable passages of a cold branch of the recuperator and are thereby warmed while an equalizing portion of the gas mixture or the rectification products is withdrawn from an intermediate portion of the regenerator and is passed through the warm branch of the recuperator for heating therein to ambient temperature.

The system of the present invention thus comprises, in combination with an air rectification column of the Linde Frankl type and means for the work expansion of the gas, e.g. an expansion turbine, of a heat exchange system, comprising two functionally interchangeable or switchable regenerators and a recuperator having a warm branch and a cold branch and provided with at least two functionally interchangeable compartments and at least two functionally fixed or nonswitchable compartments.

This system provides, in one embodiment, that impure compressed air, constituting the major portion of the compressed gas requirements of the installation, is passed through a previously cooled regenerator from its warm end to its cold end to transfer heat to the heat storage mass concurrently with the deposition by condensation and solidification of impurities within this regenerator. During the same half-cycle and in the regenerator, an impure cold rectification product is passed in heat-absorbing relationship through the device from the cold end to the warm end and serves to reduce the temperature of the heat storage mass while sweeping the volatilized condensate or sublimate from this heat exchanger (in the next half-cycle, the functions of the regenerators are reversed). While the major portion of the compressed air is passed through the previously cooled regenerators, as noted above, the remainder of the compressed air is passed through one compartment of the warm branch of the recuperator and flows through a corresponding compartment of the cold branch, this fraction of the compressed air being thereafter recombined with the purified compressed air from the regenerator. At the same time, through a nonswitched pair of compartments of the cold and warm branches of the recuperator, the pure air rectificaton product is passed while a fraction of the impure air rectification product (i.e. nitrogen) is passed in the same direction through the cold and warm branches in respective compartments of each.

According to the essential feature of the invention mentioned earlier, an equalizing portion of the impure nitrogen traversing the regenerator system is withdrawn at an intermediate location of this regenerator, between its warm and cold ends, and is led through a compartment of the warm branch of the recuperator which is permanently assigned thereto. Similarly, a compartment of the cold branch of the recuperator is assigned to a fraction of the compressed air to be subjected to work expansion in one embodiment of the present invention.

In the aforedescribed manner, air rectification can be carried out in the same way with recuperators as has been possible heretofore with tube coils in regenerators and the combination of recuperators and regenerators permits the complex tube coil regenerators to be dispensed with and nevertheless maintains the temperature difference at the cold ends at a low level as is highly advantageous for vaporization or sublimation of impurities. During the cold period, a fraction of the impure nitrogen or the impure compressed air is withdrawn from the regenerator and passed through a nonswitchable compartment of the warmer branch of the recuperator and is thereby heated to ambient temperature, while in the cool branch of the recuperator, the compressed gas to be work expanded or a fraction thereof is heated to increase its energy in the nonswitched portion of the cold branch of the recuperator. Regenerators and recuperators which may be used in accordance with this invention are described in the commonly assigned copending applications Ser. No. 754,087 filed 20 Aug. 1968 (now U.S. Pat. No. 3,540,531 of 17 Nov. 1970), Ser. No. 719,929 filed 9 Apr. 1968)(now U.S. Pat. No. 3,464,679 of 2 Sept. 1969) and Ser. No. 522,570 filed 24 Jan. 1966 (now U.S. Pat. No. 3,464,679 of 2 Sept. 1969).

As noted above, from the intermediate portion of the regenerators operating in the cooling phase, preferably at a location substantially midway therealong, impure nitrogen is withdrawn and diverted from the rest of the regenerator-cooling. medium, under the control of a cold valve. However, a corresponding operation according to the present invention, in another embodiment thereof, provides for removal of a fraction of the compressed air from the regenerator during the warming phase at an intermediate location along the regenerators and passing this withdrawn fraction through the warm branch of the recuperator to heat this fraction to ambient temperature and the subsequent compression of the warmed fraction prior to returning it to the compressed-air stream which is to be cooled in this regenerator. The post compression compensates for the pressure drop in the passage of the withdrawn fraction to the warm branch of the recuperator.

In this manner, about 5—10 percent of the compressed air traversing the regenerator and about 3—6 percent of the total compressed air is circulated through the warm end of the regenerator and the warm branch of the recuperator in a closed path. The pressure drop along this recycling path then amounts to several tenths of an atmosphere and the increase in energy required by the post compression of the recirculated stream amounts to less than 0.5 percent of the total energy imparted to the compressed gas mixture. Moreover, the system has the advantage that the admixture of dry compressed air removed from an intermediate zone of the regenerator with the impure compressed air about to enter the latter, reduces the water-vapor saturation of the compressed air before it enters the cool zones of the recuperator and/or the regenerator. The use of a post compression stage for the recirculated compressed air provides a highly effective technique for controlling the amount of fluid removed from the intermediate section of the regenerator. In this case, the compressor acts as a control means and the cold valve can be omitted.

Both techniques for withdrawing the equalization stream of fluid adapted to be passed through the warm branch of the recuperator can also be used to adjust, in the recuperator, the proportion of incoming compressed air to outflowing rectification products which are used to cool the compressed air to compensate for the increasing specific heat of the compressed air as the specific heat rises with lowering temperatures. Thus the sensitive heat exchanger can be set for the most ad-

vantageous temperature differential for each temperature range with relative ease. Upon the development of thermal-load or fluid-volume fluctuations, the regulation of the equalizing stream is so effected that the sensitive recuperators (with minimal heat storage capacity and thereby reduced thermal inertia) maintain the temperature differential in the warm and cold branches substantially invariable while the high-thermal capacity of the regenerators is used to equalize and damp such fluctuations in the quantity of thermal energy exchange between the compressed air and the rectification products.

Since the temperature of the fraction of the gas withdrawn from the intermediate section of the regenerator varies in the course of each half cycle in which the regenerator is effective, I may provide means for adjusting the temperature, such means preferably including two taps at spaced apart locations along the regenerator for withdrawing relatively warm and relatively cool fluid therefrom, the taps merging in a mixing conduit. The withdrawal of nitrogen from the regenerator leads to a gradual decrease in the temperature with time whereas the withdrawal of compressed air increases the temperature during the warming period. When two or more regenerator groups with offset switchover periods are used, the fluctuations in the temperature are reduced. In this case, the double-tap arrangement is provided nevertheless to further reduce or eliminate temperature variations. The control valves or the like, regulating the quantities of the warm and cold fluids tapped from the regenerator can be responsive to temperature or provided with timer or programming systems.

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is a flow diagram of a system for the heat exchange of gas fractions and a gas mixture and from which impure nitrogen is derived from the midsection of a regenerator, in accordance with the principles of the present invention; and

FIG. 2 is a central view of another system embodying the principles of the present invention.

In FIGS. 1 and 2, I show systems which may be used for effecting heat exchange between a relatively warm gas and cold gas fractions, in accordance with the principles of the Linde-Frankl air rectification system in which atmospheric air, containing nitrogen, oxygen, water vapor, carbon dioxide, possibly other impurities and inert gas fractions is rectified to produce, as major products, relatively pure oxygen and relatively pure nitrogen. Systems of this type are described in the above-mentioned U.S. Pats. The rectification column is not shown in FIGS. 1 and 2 although it will be understood that the column effectively separates the gas mixture and produces relatively cold pure and impure gas fractions upon the portion of the column which is tapped.

The heat exchange system of the present invention comprises a pair of regenerators 1 and 2 as well as a recuperator system 3 having a cold recuperative branch 4 and warm recuperative branch 5. The system is intended to be reversible, i.e. warm gas passes through the regenerator 1 to extract cold from the heat storage mass therein and warm the regenerator during one half of a cycle while a cold gas is passed through the regenerator during the subsequent half-cycle to store cold therein or abstract heat therefrom. While regenerator 1 operates in one half-cycle mode, regenerator 2 operates in the other half-cycle mode. The system for switching the various heat exchange elements, control circuits, temperature sensing devices and the like, all of which may be of the type hitherto provided in heat exchange systems for air rectification installations, have been omitted to avoid obscuring the distinctions between the present system and earlier systems. Moreover, when I refer to "regenerators" herein, it is my intention to refer to heat exchange units containing heat storage masses of high-thermal capacity which store heat or cold during one operating mode and are traversed via the same passages by a subsequent fluid to which they give up heat or cold. Similarly, "recuperators"are, in accordance with the principles of the present invention, indirect heat exchangers, preferably plate-type heat exchangers with low thermal capacity intrinsically and low thermal inertia, in which the simultaneous flow of fluids through two separate compartments, passages or chambers, bring the streams into heat-exchanging relationship through a thermally conductive wall separating the two chambers. Both recuperators and regenerators, therefore, are "indirect" heat exchangers in the sense that heat transfer is not effected by molecular transfer of energy between two fluids in direct contact with one another. In the regenerative system, however, the thermal energy or capacity to absorb thermal energy is temporarily stored in a solid as a result of fluid solid transfer and thereafter is transferred to another fluid by a solid fluid path. In a recuperator, there is practically no intervening thermal storage and the heat transfer path can be represented as a fluid solid fluid continuum.

The recuperator system 3 is subdivided into a cold section 4 and a warm section 5, each section having four passages represented at 4*a*, 4*b*, 4*c* and 4*d* and at 5*a*, 5*b*, 5*c* and 5*d*, respectively.

Impure air, i.e. am ambient air mixture, may be admitted through line 50 and will, of course, contain impurities which must be removed from this gas mixture prior to rectification thereof.

It may be noted at this point that the system will be described for one-half cycle of the fluid flow and that reversal of function will occur during the second half-cycle. The valves which allow the impure air mixture to pass through generator 2, etc. and which are provided in a functional-interchangeable system as described in the last-mentioned patents, have been omitted to avoid obscuring the drawing. Line 50 leads into the warm end 1*a* of the regenerator 1 whose cold end 1*b* is connected via a line 51 and a check valve 10 to the air rectification installation which may be a Linde-Frankl column as described in the aforementioned patents and which is represented at 52 in dot-dash lines. A line 53, branched from line 50, leads a minor fraction of the impure gas mixture, i.e. impure air which may or may not have been pretreated to remove impurities, to the line 5*c*, 4*c* of the warm and cold recuperator sections 5 and 4, in succession; check valve 12 is provided in the line 53' prior to the point at which this branch rejoins line 51 at 54.

From the air rectification installation 52, a line 55 leads impure cold gas via the check valve 11 through the cold end 2*b* of the second regenerator 2, operating in interchangeable functional relationship with regenerator 1. At the warm end 2*a* of the regenerator 2, a line 56 provided with valve 7 conducts the impure nitrogen from the system. A portion of the cold gas stream, is passed through the lines 56, the check valve 13 and the chambers 4*b*, 5*b* of the cold and warm recuperator sections 4 and 5, in succession, prior to emerging at a line 57 provided with the valve 9.

The lines 8, 5*c*, 4*c* and 53' are functionally interchangeable with lines 9, 5*b*, 4*c* and 56' as impure-gas passages, the alternate has cycles passing impure air and flushing cold gas through these passages.

A pure gas (e.g. oxygen or nitrogen) derived from the air rectification system 52 is led at 14 through the compartments 4*a* and 5*a* of the cold and warm recuperator sections 4 and 5, in succession, and is led at 15 as a somewhat warmer gas from the system. The passages 4*a*, 5*a* are not functionally interchanged with any other and are constantly used to pass the pure gas in heat-exchanging relationship with the other fluids.

An adjustable fraction of the previously cooled compressed air, derived via line 57 from the rectification installation 52 in known manner, prior to further cooling by work-producing expansion at, for example, an expansion turbine, represented at 58, is bypassed through a nonswitchable compartment 4*d* of the cold branch of the recuperator 3. This portion is tapped at 16 from line 57, is passed through the compartment 4*d* and returns via line 17 and a mixing valve 18 to the line 57 which carries the cold gas mixture to the expansion turbine.

The bypassed portion of the cold gas mixture, which has previously been freed from high boiling point impurities, is somewhat warmed to a median temperature, i.e. a temperature of the air in chamber 4*c*, and the temperature of the air passing through line 57, and is mixed at 18 with the remainder of the air led to the work expansion stage.

The equalizing flow between the regenerators 1 and 2 and the warm branch 5 of recuperator 3 is tapped at 18*a* from an intermediate portion of the regenerator 2 as controlled by a valve 19. Of course, a similar tap will be provided on the regenerator 1 so that the equalizing stream may be withdrawn from this regenerator when the regenerators 1 and 2 are functionally interchanged for the last half-cycle of the heat exchange process. In this embodiment, the equalizing stream is a portion of the impure nitrogen and is removed during the period in which regenerator 1 is being warmed by the compressed air traversing same and is imparting cold to this fluid, the regenerator 2 being operated in its cooling mode during this period. In the cooling period, nitrogen from line 55 is passed through the regenerator 2 to absorb stored heat from the heat storage mass therein and bring the regenerator to the temperature desired for the subsequent cooling of the compressed air. The equalizing stream is thus a portion of this impure nitrogen and is passed via cold valve 19 and a line 20, through a nonswitched passage 5*d* of the warm branch 5 of the recuperator 3. From the passage 5*d*, the impure nitrogen removed at an intermediate temperature, i.e. at a somewhat warmer temperature than the nitrogen entering the cold end of the heat exchanger and somewhat lower temperature than the nitrogen leaving the warm end 2*a*, can also be mixed with the impure nitrogen stream traversing the switchable impure passages of the recuperator 3 between the cold branch 4 and warm branch 5. Such mixture may be effected via a valve 61 and a branch 62 which is optionally provided as indicated in dot-dash lines in FIG. 1. The proportions can then be established in lines connecting regenerators 1 and 2 and the recuperator 3.

FIG. 2 shows schematically a system differing from that of FIG. 1 in that the equalizing stream is compressed air withdrawn during the warming phase of the regenerator cycling instead of nitrogen drawn from the regenerator during the cooling phase as in FIG. 1.

In the system of FIG. 2, reference numerals 1—18, 20 and 21 correspond to the similarly numbered elements of FIG. 1. In this embodiment, however, the regenerators 1 and 2, provided with check valves 10 and 11 as previously described but poled in the opposite direction, are disposed at spaced apart locations at intermediate zones of these regenerators with taps 18*b* and 18*c*, located respectively to the warm and cold sides of the intermediate zone at which the desired temperature of the gas fraction removed from the regenerator is sustained.

The taps 18*b* and 18*c* are provided with respective check valves 19*b* and 19*c* permitting fluid flow only out of the regenerator to a mixing valve 24. The mixture of relatively cold, relatively warm gases at an intermediate temperature passes via the lines 20 and 21 through the warm branch 5 of the recuperator 3, the chamber 5*d* traversed by this bypassed portion of the compressed air being nonswitched.

In the compartment 5*d*, the bypassed fraction of the compressed air is heated to the transformation temperature and, thereafter, is subjected to post compression in a compressor 22*a* before being returned at 22*a*′ to the incoming compressed air duct 23. Upon its return to the compressed air inlet line, which is branched at 23 from the line 50, the recirculated air reduces the relative humidity of the air about to enter the recuperator 3 via the switchable passage 5*c*, 4*c* thereof. This embodiment indeed increases the heat and air throughout of the warm section of the regenerator but it eliminates the need for a cold valve as shown at 19.

By the withdrawal of the equalizing gas stream from two spaced apart taps during the course of a single half-cycle of the operation of the apparatus of FIG. 2, it is possible to control the temperature of the gas passing through the recuperator 5 to maintain the latter substantially constant. A temperature sensitive element 24′ may be connected to a thermostatic control 24″ which, in turn, controls the mixing valve 24. The withdrawal of compressed air from the central section of the regenerators 1 and 2 is so adjusted that, at the commencement of the warming period of the regenerator 2, for example, the major portion of the compensating stream is withdrawn from tap 18*b* via the check valve 19*b*, close to the warm end of the regenerator.

During the course of the heating period, the temperature of the gas withdrawn at the tap 18*b* increases and proportionately more of the compressed air is withdrawn through tap 18*c* with a corresponding diminution of the quantity withdrawn at tap 18*b*. The temperature at entry of the equalizing stream into the warm branch 5 of the recuperator 3 remains substantially constant. While the system of FIG. 2 has been illustrated for a system in which compressed air serves as the equalizing stream in place of the impure nitrogen of the system of FIG. 1, it will be understood that a double-tap arrangement such as that shown at 18*b* and 18*c* can be used in place of single tap 18*a* of the system of FIG. 1.

EXAMPLE

Using the system of FIG. 1, in conjunction with an air rectification installation capable of extracting 10,000 m.³/hr. (S.T.P.) of pure oxygen from 52,000 m.³/hr. (S.T.P.) of compressed air to be rectified, after deduction of switching losses for the regenerators and recuperators, the pure oxygen stream is passed through the nonswitched compartments 4*a* and 5*a* of the cold and warm branches 4 and 5 of the recuperator 3 exclusively and is obtained at line 15 as warm O_2. The entire complement of impure nitrogen obtained from the air rectification installation is derived at line 55 and split between the regenerators and the recuperators. In one-half cycle, therefore, the recuperator compartments 4*b* and 5*b* are traversed by part of the impure nitrogen stream in the direction of the arrow shown in FIG. 1 while the balance of the impure nitrogen passes through the regenerator 2 to cool the latter. At the upper end of the regenerator and from recuperator chamber 5*b*, warm impure nitrogen is obtained.

According to the present invention the equalizing nitrogen stream is shunted at 18*a* through only the warm branch 5 of recuperator 3. During the subsequent half cycle of the periodic process, the impure nitrogen stream is split between the regenerator 1 and the recuperator chambers 4*c* and 5*c*. Conversely, the first-mentioned half-cycle of switching period sustains a compressed air flow which is split between the regenerator 1 (from warm end to cold end) and the recuperator 3, the branched compressed air stream traversing the warm and cold recuperator sections 5 and 4 in succession.

Under the assumption that to insure complete vaporization or sublimation in the functionally interchangeable (switchable) gas paths at the same temperature, the withdrawn volume should amount to about twice the input volume, whereby an adequate evaporation or sublimation can be effected even in the presence of localized or temporarily increased temperature differentials, the pressure ratio of the inflowing gas stream to the outflowing gas stream for an average gas pressure of 5.76 atm. (absolute) of the inflowing gas and 1.20 atm. (absolute) will be about 4.80

$$\left(\frac{5.76 \text{ atm. A.}}{1.20 \text{ atm. A.}} = 4.80\right).$$

Since at the same temperature the inflow volume should be twice the outflow volume the ratio

$$\frac{\text{Volume in}}{\text{Volume out}} = \frac{1}{2} = \frac{1 \text{m}^3\text{/hr. (STP) in} \cdot 1.2}{5.76 \cdot \times \text{m}^3\text{/hr. (STP) out}}$$

must be satisfied. From this ratio, x can be seen to be 0.417 m.³/hr. (STP) outflow per m.³/hr. (STP) of inflow when the 3/hr. gas pressure is 1.2 and the inflow pressure is 5.76 atm. The second postulate is that through the cold parts of the

regenerators and recuperators 8 to 10 percent more expanded rectification products should be withdrawn than compressed air admitted to the system, thereby compensating for the higher specific heat of the compressed air in the cold portions.

Both of these assumptions are satisfied when, 10,000 m.³/hr. (S.T.P.) of pure oxygen is passed through the recuperation branches **4** and **5** as illustrated, 52,000 m.³/r. warm compressed air (which, deducting switching losses, produces this quantity of oxygen) yields 30,650 m.³/hr. (STP) to the regenerator **1**, **2** and 21,350 m.³/hr. (STP) to the recuperator **3**.

An additional equalizing or compensating stream of 2,350 m.³/hr. (S.T.P.) of impure nitrogen flows together with the 30,650 m.³/hr. (S.T.P.) mentioned earlier through the cold portion of the regenerators **1**, **2** and is withdrawn from the intermediate portion of the regenerators **1**, **2** as controlled by the valves **19**, **22** and led through the nonswitched compartment **5***d* of the warm branch of the recuperator **3** along the path **20**, **21** in which this equalizing stream is heated to approximately ambient temperature. This dry gas, which may contain some carbon dioxide, can then be used as a heating medium.

Through the nonswitched compartment **4***d* of the cold branch **4** of recuperator **3**, along the path **16 — 18**, approximately 4,000 m.³/hr. (S.T.P.) of the compressed air which is to be subjected to work expansion is led and constitutes the gas stream necessary for heat balance in this cold branch of the heat exchanger. In the absence of this portion of the gas, the higher specific heat of the compressed air which is cooled in the cold branch **4** gives rise to a large temperature difference at the cold end of the recuperator and prevents full removal of carbon dioxide in the sublimation and vaporization phases. In the warm portions of the regenerator and in the warm branch of the recuperator, a quantitive balance exists between the compressed air and the withdrawn gases. In the cold part of the regenerator and in the cold branch of the recuperator, the compressed air is present in an amount of about 7.7 percent larger than the gases warmed therein.

I claim:

1. In a heat exchange system for the rectification of a gas mixture into at least two components and in which part of the cold to be imparted to the gas mixture is derived from the work expansion of the gas mixture or a gas rectification product, the method which comprises the steps of:

passing a portion of the warm gas mixture to be subjected to rectification as a warming medium and a portion of a product of gas rectification as a cooling medium alternately through regenerative heat exchange means including at least one regenerator, thereby cooling said portion of said gas mixture and warming said portion of said rectification product;

simultaneously passing another portion of the warm gas mixture and said rectification product through a common recuperator in heat-exchanging relationship with one another through the walls of said recuperator, said recuperator being subdivided into warm and cold branches successively traversed by the warm gas mixture and the rectification product in opposite directions;

warming a part of the gas to be work expanded in said cold branch of said recuperator; and

withdrawing from an intermediate location of said regenerator, a portion of the medium passed therethrough and heating same in said warm branch of said recuperator approximately to ambient temperature.

2. The method defined in claim **1** wherein said recuperator has at least one pair of switchable chambers respectively traversed alternately by said other portions of the warm gas mixture and rectification product, and at least one nonswitchable chamber in heat-exchanging relationship with the first-mentioned chambers and traversed by the portion of the medium withdrawn from said intermediate location of said regenerator, said method further comprising the step of switching the flows of gas between said first-mentioned chambers upon the precipitation in the chamber traversed by the warm gas mixture of high boiling impurities,

3. The method defined in claim **1** wherein said part of the gas warmed in said cold branch of the recuperator is recombined with the remainder of the gas from which said part was derived.

4. The method defined in claim **1**, further comprising the step of post compressing said portion of said medium after heating same in said warm branch of said recuperator and recombining said portion of the medium with the medium from which it was derived.

5. The method defined in claim **4** wherein the t portion of said medium is mixed with said other portion of said warm gas mixture prior to its passage through said recuperator.

6. The method defined in claim **1** wherein said portion of said medium is tapped at least at two spaced apart locations from said regenerator with the tapped portions being combined prior to entering said warm branch of said recuperator.

7. The method defined in claim **6** wherein the medium collecting at said taps is mixed in proportions such that the portion of the medium heated in said recuperator enters the latter at substantially constant temperature.

8. A heat exchange installation for a gas rectification plant, comprising:

a pair of regenerators alternately traversable by a warm gas mixture to be rectified and rectification product capable of cooling the regenerators;

a recuperator having a warm and a cold branch traversed in succession by further portions of said mixture and said rectification product in opposite directions;

means for passing a work expandable gas through said cold branch of said recuperator;

and means for withdrawing from an intermediate location along at least one of said regenerators, the medium traversing same and for passing the withdrawn medium through said warm branch of said recuperator for heating therein.

9. The installation defined in claim **8** wherein the last-mentioned means includes a pair of taps spaced apart along said one of said regenerators, and temperature-controlled mixing means between said tap and said warm branch for maintaining the temperature of the medium admitted to said warm branch substantially constant by appropriately mixing the portions of said medium derived from said taps.

10. The installation defined in claim **8** wherein said warm branch of said recuperator has a pair of functionally interchangeable compartments respectively traversed by said rectification product and said mixture in alternate succession during successive half cycles of the operation of the recuperator, and at least one nonswitchable compartment traversed by the portion of said medium withdrawn from said regenerators.

11. The installation defined in claim **10**, further comprising postcompression means between said nonswitchable compartment and the compartment traversed by said warm gas mixture.