

Dec. 27, 1949

W. DENNIS
REGENERATOR

2,492,788

Filed May 24, 1947

2 Sheets-Sheet 1

FIG. 1

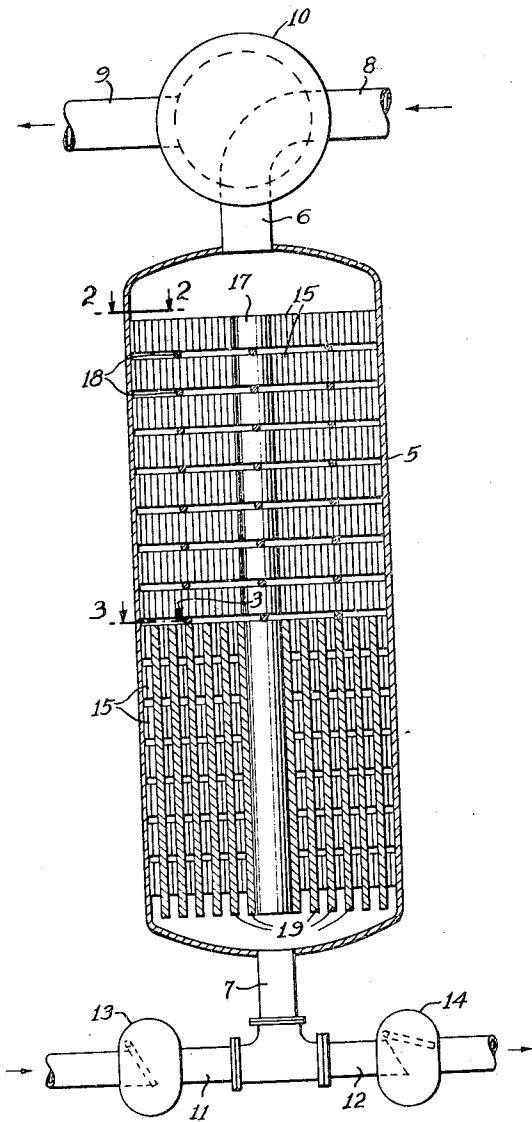


FIG. 2

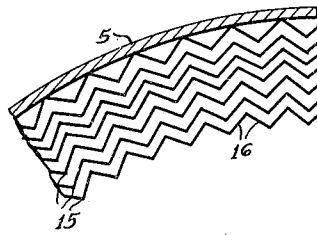
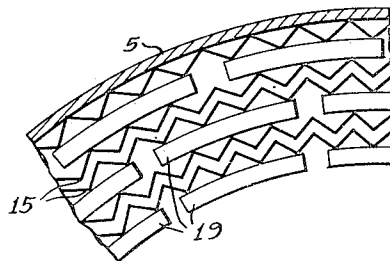


FIG. 3



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FIG. 4

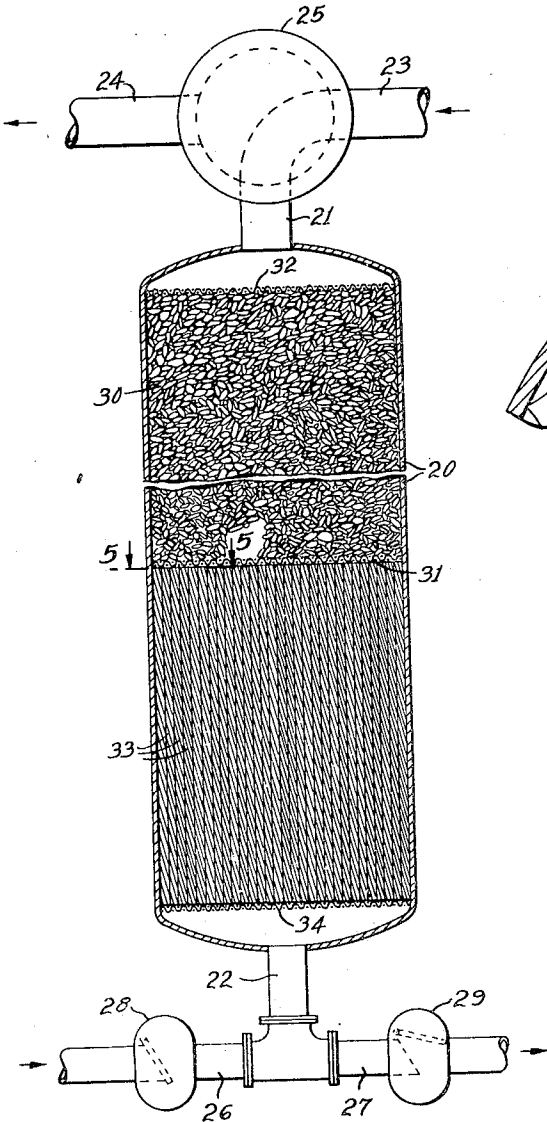


FIG. 5

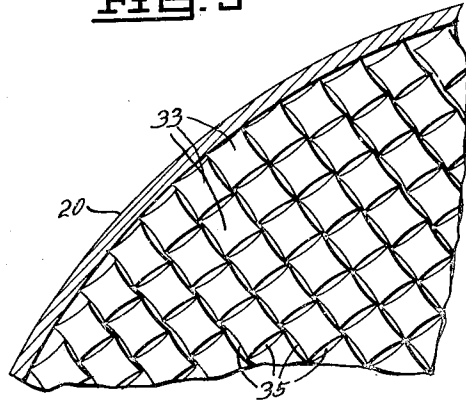
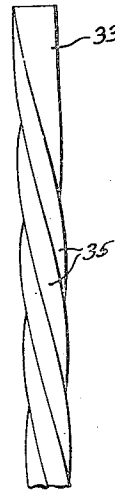


FIG. 6



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2,492,788

REGENERATOR

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Application May 24, 1947, Serial No. 750,234

5 Claims. (CL 257—6)

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This invention relates to improvements in apparatus for cooling a fluid by transfer of heat to a heat absorbing mass, the temperature of which has been reduced in warming another fluid from a low temperature as exemplified in the patent to Frankl No. 1,890,646 in which such a system is employed in the separation of a gaseous mixture into its constituents by liquefaction.

The devices employed for the purpose described are ordinarily referred to as regenerators or accumulators. In liquefaction processes employing such regenerators, air ordinarily passes in through the nitrogen regenerator at about five atmospheres pressure, and nitrogen is exhausted through the regenerator at about 1 atmosphere pressure so that the volume ratio of nitrogen to air passing through any temperature level in a regenerator is about 5-1. In order to achieve complete revaporization and removal of carbon dioxide deposited from the air, the vapor pressure of the carbon dioxide at the nitrogen temperature cannot be less than one-fifth that corresponding to the temperature of the air at the point of deposit, since 5 volumes of nitrogen would then contain just as much carbon dioxide as was brought in by 1 volume of air. With equal mass flows of air and nitrogen, this equalization of carbon dioxide carrying capacity occurs at a temperature level where about 10% of the carbon dioxide still remains in the air, and at colder temperatures carbon dioxide deposits are incompletely revaporized due to insufficiently high vapor pressures at the nitrogen temperature. As a result, the regenerator eventually becomes choked with solid carbon dioxide and must be warmed to eliminate this material.

One method of altering the conditions in the zone where carbon dioxide is not completely revaporized consists of the addition of a small increment of flow to the outgoing nitrogen so that it has a greater heat capacity in relation to the entering air. This results in lower air temperature at the level corresponding to any given nitrogen temperature in the colder zones of the regenerator or a higher nitrogen temperature at the level of any corresponding cold region air temperature. Obviously the zone of complete carbon dioxide removal has thus been extended to a lower temperature level, and carbon dioxide revaporization is more nearly complete.

This proposed method has several disadvantages in that the incremental flow of nitrogen must be supplied by introducing an auxiliary air supply without passing it through the regenerator. It must be dry and free from carbon dioxide

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and therefore require some means for elimination of these impurities. Also, the closer approach of air and nitrogen temperatures at the cold end of the regenerator attained by this method results in further separation of the air and nitrogen temperatures at the warm end and the consequent loss of refrigeration in the method.

Another proposed method of overcoming the difficulty experienced with regenerators involves removing a portion of the air stream at about the mid-point of the regenerator. The reduced quantity of the remaining air contains less total carbon dioxide and the temperature approach of the remaining air is closer to that of the nitrogen so that any carbon dioxide frozen out is easily revaporized by the larger nitrogen stream. This again requires a purification system for that part of the air which is withdrawn at the mid-point of the regenerator, since otherwise the carbon dioxide and moisture present therein will be carried over into the liquefaction system. Even though the total amount of carbon dioxide is small, it may nevertheless introduce difficulties in the system.

It is the object of the present invention to provide an improved apparatus for effecting the desired heat transfer while ensuring more complete revaporization of solids deposited from the incoming fluid such as air during that part of the cycle when the outgoing fluid such as nitrogen passes through the regenerator.

Other objects and advantages of the invention will be better understood by reference to the following specification and the accompanying drawing, in which

Fig. 1 is a longitudinal section through a regenerator embodying the invention;

Fig. 2 is a section on the line 2-2 of Fig. 1;

Fig. 3 is a section on the line 3-3 of Fig. 1;

Fig. 4 is a longitudinal section through a modified form of the regenerator;

Fig. 5 is a section on the line 5-5 of Fig. 4; and

Fig. 6 is a view in perspective of a heat transfer element.

Referring to the drawing, 5 indicates a tubular shell of any suitable metal having outlets 6 and 7 at the top and bottom thereof. Air, for example, is adapted to be introduced through a pipe 8 at the top of the regenerator, and nitrogen, for example, may be exhausted through the pipe 9. A valve 10 is adapted to be reversed from time to time so that air and nitrogen pass alternately through the regenerator. At the bottom of the regenerator, pipes 11 and 12 afford an inlet for nitrogen and an outlet for air. Valves 13 and

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14 may be manipulated in proper sequence with the adjustment of the valve 10 to direct the flow of the fluids alternately through the regenerator.

The shell 5 of the regenerator is substantially filled with a plurality of coils 15 of corrugated metal 16 of copper, aluminum or the like wound about cores 17. While I prefer to employ filling elements similar to those described in Frankl Reissue Patent No. 19,140, any suitable filling material which is adapted to effect heat transfer between the fluids passing through the regenerator may be employed. Preferably the coils 15 are separated by spacers 18, although this is not essential to the invention because even if the coils are in direct contact the heat flow between them is relatively limited, owing to the insulating effect of the film of gas between the metal surfaces which may be in contact.

In accordance with the present invention, I provide in the lower section of the regenerator a plurality of elongated members 19 of metal having a high heat conductivity coefficient such as copper, aluminum, or the like. The members may be in the form of rods, bars, sheets or similar elements having sufficient mass and surface to effect heat transfer between the several coils 15 in the lower section of the regenerator. Heat will thus flow from the warmer region to the colder end of the regenerator, tending thus to raise the temperature of the coils 15 at the lowermost or colder end and lower the temperature of the rods at their upper ends.

Assuming that the regenerator has already been cooled by passage of nitrogen upwardly therethrough to an adequately low temperature, the flow of nitrogen is shut off and air is introduced from the pipe 8. Flowing downwardly through the regenerator, the air is cooled by heat transfer to the metal of the coils 15. The air will be cooled to a lower temperature in the upper portion of the zone containing the rods 19 than it could reach if the packing were not conductive and moisture and carbon dioxide therein will be congealed and deposited on the metal surfaces. At the proper time, the flow of air is shut off, and nitrogen is again conducted through the regenerator. The nitrogen, in passing upwardly, is warmed to a warmer temperature in the lower portion of the regenerator including the rods 19, than it could reach if the packing were not conducting heat to it from a higher zone.

At approximately the mid-point of the heat conducting zone of the regenerator, both effects have reached a maximum, and the temperature of the air depositing carbon dioxide is much closer to the temperature of the nitrogen vaporizing the carbon dioxide than would be possible with the usual type of regenerator having no substantial heat transfer between the coils 15. At all points within the zone in which conductive packing is installed, the temperature difference between the air depositing carbon dioxide and the nitrogen revaporizing the carbon dioxide is less than would be the case if no provision were made for lengthwise heat conduction. This closer approach of the air and nitrogen temperatures results in a relative increase in the carbon dioxide vapor pressure at the nitrogen temperature as compared with the carbon dioxide vapor pressure at the corresponding air temperature. Hence, the nitrogen is able to revaporize and carry out of the regenerator a greater proportion of the carbon dioxide, carried to any point of this zone by the air, than would be the case if no lengthwise heat conduction were provided.

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By the installation of a sufficient number of conductive elements in the cold zone of a regenerator, extending from a temperature level of about -200° F. to the cold end, the temperature approach of the air and nitrogen in this zone can be brought sufficiently close so that complete revaporization and removal of deposited carbon dioxide may be effected except in the very coldest parts of the regenerator. In these parts so little carbon dioxide remains in the air (less than 0.2% of normal carbon dioxide content) that no operating difficulty results.

The design of conductive packing for any particular case will depend on the degree of temperature approach required, the type of packing chosen for the warm end and the quantity of flow per unit area of the regenerator. To be effective, there must be sufficient heat transfer surface and mass to carry out the normal function of regenerative packing and compensate for the lower mean temperature difference resulting when lengthwise heat conductive elements are used. The packing material and its total cross-section area must be selected to conduct the heat necessary to produce the required temperature differentials, particularly in the upper part of the conductive zone where the greatest concentration of carbon dioxide exists.

In Figs. 4 to 6, a modified form of the regenerator is shown in which a tubular shell 20 of any suitable metal is provided with outlets 21 and 22 at the top and bottom thereof. Air, for example, is adapted to be introduced through a pipe 23 at the top of the regenerator, and nitrogen, for example, may be exhausted through the pipe 24. A valve 25 may be reversed from time to time so that air and nitrogen pass alternately through the regenerator. At the bottom of the regenerator pipes 26 and 27 afford an inlet for nitrogen and an outlet for air. Valves 28 and 29 may be manipulated in proper sequence with adjustment of the valve 25 to direct the flow of the fluids alternately through the regenerator.

The shell 20 of the regenerator is partially filled with a heat transfer material 30 such for example as a multiplicity of small pieces of metal supported in a screen 31. A screen 32 may be disposed above the heat transfer material. Aluminum or copper are preferred, but other materials may be used. Conveniently, the material may be in the form of balls or pellets of regular or irregular shape, which afford a multiplicity of gas passages between them. The size may be approximately one-eighth to one-quarter inch in diameter, but larger or smaller pieces may be used. The heat transfer material 30 is alternately cooled and warmed by the passage of the fluid there-through.

At the lower or cold end of the regenerator, a plurality of elongated members 33 of metal having a high heat conductivity coefficient such as copper, aluminum or the like are disposed in the space beneath the filling of heat transfer material. The members 33 may be supported by a screen 34. The members 33 may be in the form of rods, bars, sheets or similar elements having sufficient mass and surface to effect heat transfer from the warmer to the colder ends thereof. Heat will thus flow from the warmer region to the colder end of the regenerator, tending to raise the temperature at the lowermost or colder end.

Conveniently the members 33 may be formed by twisting rods of rectangular or circular cross-section about their longitudinal axes (see Fig. 6). The twisting results in the formation of helical

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grooves 35 in the surfaces of the rods. The grooves 35 facilitate the passage of fluid around and between the rods. The invention is not, however, limited to the use of rods in this particular form, since it depends, as hereinbefore indicated, upon the provision of means to transfer heat from an intermediate to a colder region of the regenerator.

The operation of the modification last described is substantially as in the preceding embodiment of the invention. Therefore it is unnecessary to repeat the description of such operation. The resulting advantage is the same.

The apparatus as described affords an effective solution of the problem of revaporizing the deposited carbon dioxide from the metal surfaces of the regenerator by the available flow of nitrogen. It is thus unnecessary to resort to expedients such as the auxiliary air stream or withdrawal of a portion of the air from the regenerator before it reaches the colder end thereof.

While the invention has been described more particularly with reference to the nitrogen regenerators, it may be utilized similarly where oxygen is employed as the cooling fluid, in which case the entering air is cooled by contact with the cold metal surfaces in the regenerator upon which it deposits moisture and carbon dioxide in solid form. The latter are re-vaporized, in this case by the flow of cold oxygen in the reverse direction through the regenerator.

Various changes may be made in the form, arrangement and structure of the apparatus without departing from the invention or sacrificing the advantages thereof.

I claim:

1. A regenerator adapted to transfer heat between streams of fluids passing alternately through the regenerator comprising a shell having a warm end and a cold end, inlet and outlet means connected to each end of the shell, heat transfer material affording a multiplicity of gas passages of relatively small cross-sectional area within the warm end of the shell, and a plurality of heat-conducting members in the cold end por-

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tion of the shell and extending longitudinally of the shell from the cold end to an intermediate section thereof, said heat-conducting members providing continuous heat-conducting paths between said intermediate section and the cold end of the shell.

2. A regenerator as set forth in claim 1 in which the longitudinally-extending heat-conducting members have helical grooves on their peripheries to facilitate the passage of fluids.

3. A regenerator as set forth in claim 1 in which the heat transfer material in the warm end portion of the shell comprises small pieces of metal and the longitudinally-extending heat-conducting members are metal rods.

4. A regenerator as set forth in claim 1 in which the heat transfer material in the warm end portion of the shell is arranged in consecutive layers.

5. A regenerator as set forth in claim 1 in which the heat transfer material in the warm end portion of the shell is arranged in consecutive layers, and in which the longitudinally-extending members are of metal having a high heat conductivity coefficient.

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