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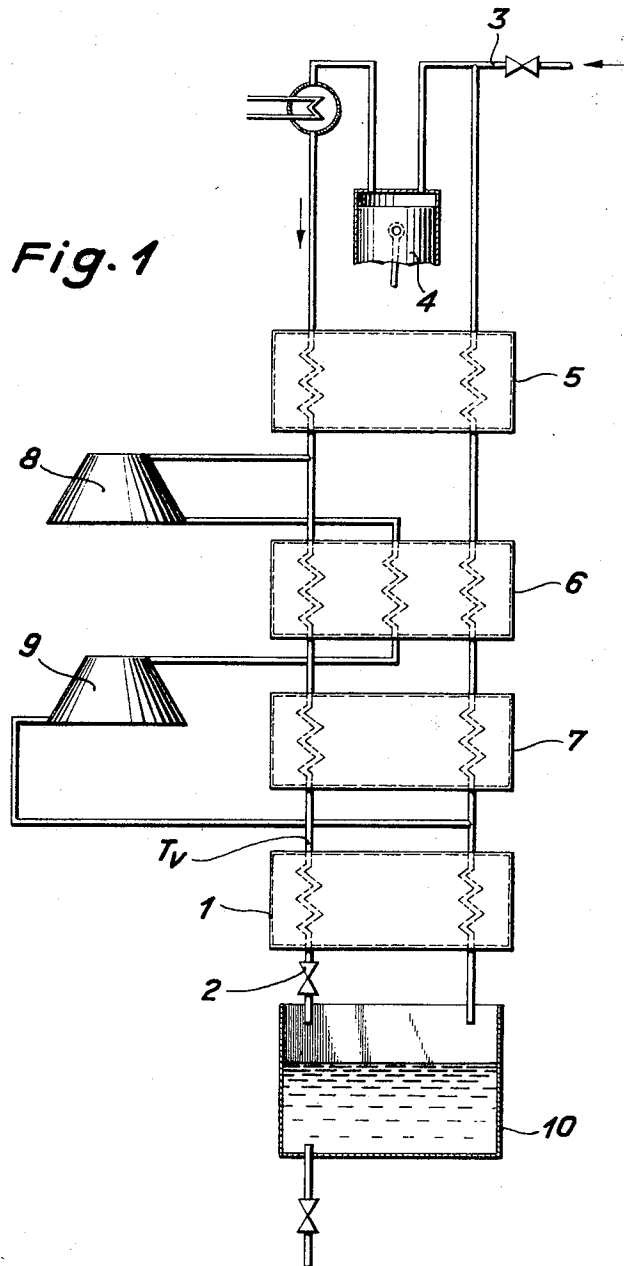
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3,396,784

HONEYCOMBED RESTRICTED TUBE HEAT EXCHANGER

Filed April 8, 1966

3 Sheets-Sheet 1



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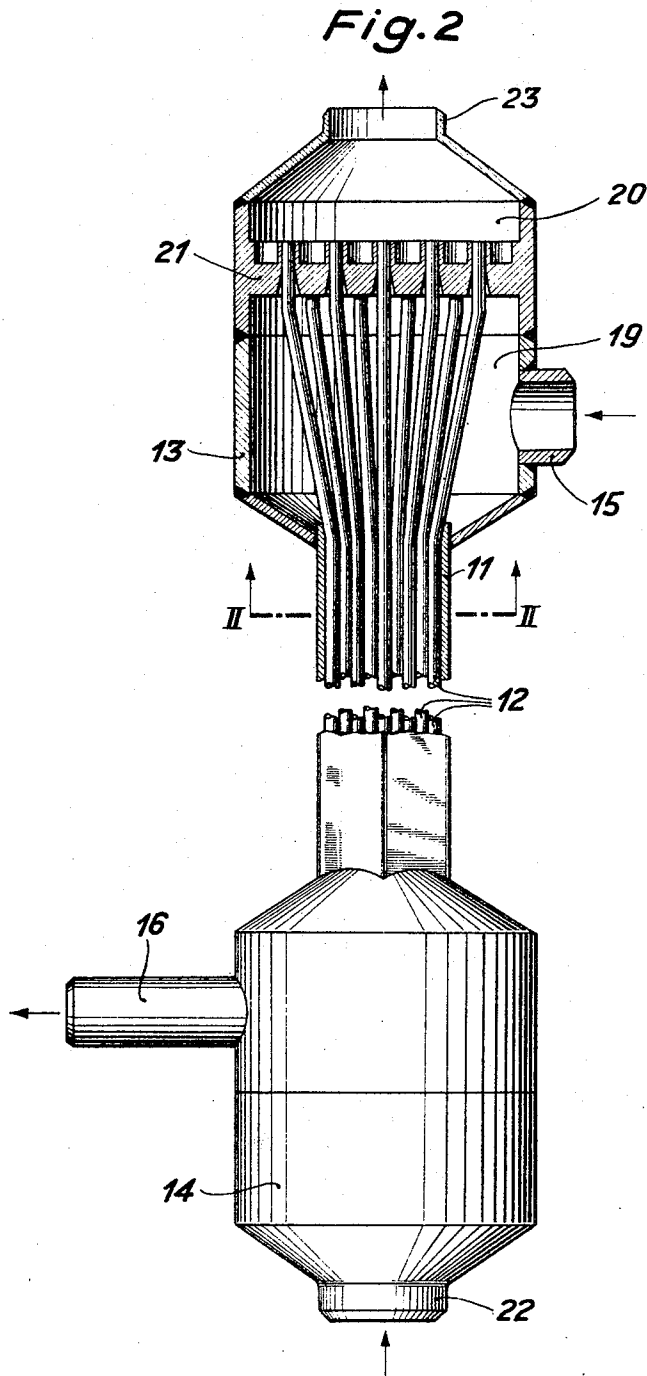
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3 Sheets-Sheet 2



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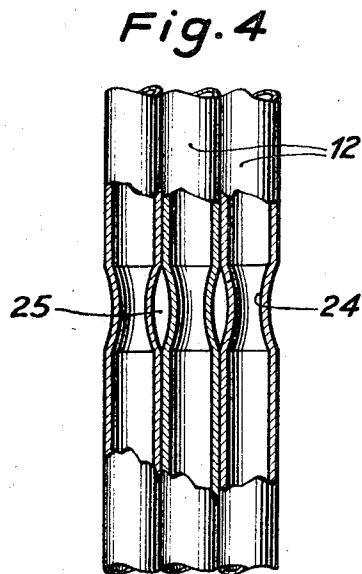
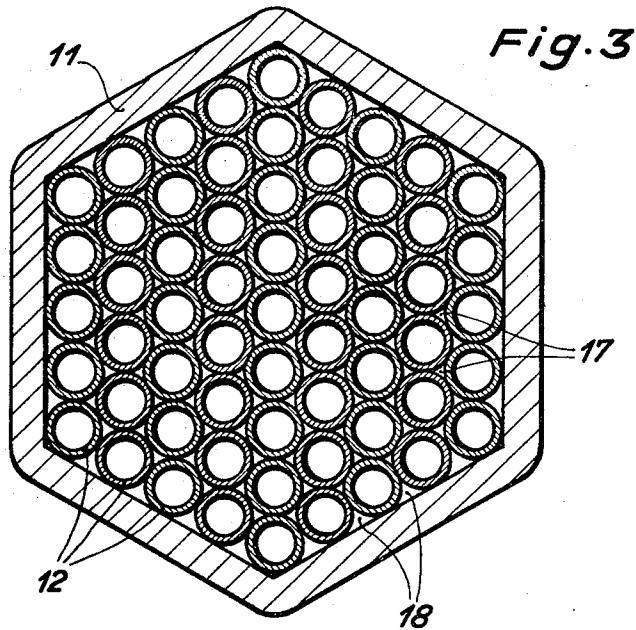
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3 Sheets-Sheet 3



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HONEYCOMBED RESTRICTED TUBE
HEAT EXCHANGER

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Filed Apr. 8, 1966, Ser. No. 541,357

Claims priority, application Germany, Apr. 17, 1965,
S 96,613

2 Claims. (Cl. 165—172)

ABSTRACT OF THE DISCLOSURE

There is disclosed a heat exchanger for use in the cooling or liquefaction of gases of low boiling point and in which, preliminary to liquefaction thereof by expansion through a throttling valve, a gas previously compressed to high pressure and cooled below its inversion temperature is further cooled by passage in countercurrent flow heat exchange relation with cooled gas at low pressure and at a temperature only slightly below that of the gas at higher pressure to be cooled. The exchanger of the invention comprises, for traversal by the low pressure cooling gas, a plurality of tubes of circular cross-section extending parallel to and in contact with each other in a honeycomb, inside a jacket of polygonal cross-section which contacts the outermost tubes of the honeycomb. The spaces of substantially triangular cross-section between adjacent tubes of the honeycomb and between the jacket and the outermost tubes of the honeycomb constitute channels which are traversed by the gas at high pressure to be cooled, and the tubes have a constriction at one point along their length inside the jacket to permit cross-flow among those channels of substantially triangular cross-section.

The present invention relates to low temperature cooling apparatus for cooling a gas of low boiling point such as hydrogen or helium to very low temperature, and preferably for liquefying it, in which the gas is compressed to high pressure, is then cooled below its inversion temperature, and then before being expanded in a throttling valve is further cooled in at least one heat exchanger by heat exchange with gas at low pressure flowing countercurrent therewith.

In installations of this kind for achievement of extremely low temperatures, the gas to be cooled, such as helium or hydrogen, is expanded through a throttling valve for achievement of the desired cooling effect at the very low temperatures in question. In the course of this expansion the gas so expanded is cooled because of the positive nature of the Joule-Thomson effect at these low temperatures, and it may be partly liquefied as well.

The compressed gas is first cooled to a preliminary cooling temperature hereinafter denoted T_v below its inversion temperature, as for example by expansion with performance of external work or by heat exchange with external refrigerants. It is then further cooled by countercurrent flow in heat exchange relation with a cooling medium expanded to a low pressure, for example the liquefaction pressure of the gas to be liquefied, before being expanded through a throttling valve. In order that cooling may be achieved by throttling at the low temperatures involved, i.e. in order that a quantity of heat corresponding to the required cooling effect may be absorbed by the cooling medium at the low temperatures involved, it is necessary that the enthalpy difference between the gas at low pressure and that at high pressure at the preliminary cooling temperature T_v , i.e., at the temperature prevailing at the hot end of the heat exchanger, be positive. The magnitude of the enthalpy difference is a measure of the avail-

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able useful cooling effect. In gases of low boiling point however such a positive enthalpy difference is achieved at these temperatures only if the temperature difference between the gases at high and low pressure is small. Temperature differences of as little as the order of 1° at the hot end of the heat exchanger may cause the Joule-Thomson effect in the throttling step to become negative, which will produce a heating rather than a cooling of the gas desired to be cooled. For example in the case of helium, at 13 atmospheres absolute pressure and at a preliminary cooling temperature of 21° K., the specific enthalpy i_1 of the high pressure gas is 117.12 joules per gram and degree. While the specific enthalpy i_2 of helium as the low pressure gas at a pressure of 1 atmosphere absolute and at 21° K. amounts to 123.07 joules per gram and degree, producing a positive enthalpy difference, the specific enthalpy of helium as low pressure gas at 19.84° K. and one atmosphere absolute is 117.00 joules per gram and degree. With a temperature difference of 1.16° at the hot end of the heat exchanger therefore, the Joule-Thomson effect upon throttling of the gas would be negative in the example suggested.

It is an object of the invention to construct a heat exchanger for application in low temperature systems as hereinbefore described which may operate effectively with differences of temperature which may be as small as of the order of less than one-tenth of a degree between the two media at the hot end of the heat exchanger.

The invention is based upon recognition of the fact that this requirement can be met with an acceptable cost of construction if precautions are taken to provide a uniform mass distribution or density of flow over the cross-section of the heat exchanger in respect of the heat exchange surfaces.

In refrigerating plants such as for example absorption plants, it has heretofore been proposed to use heat exchangers in which one of the media involved in the heat exchange passes through a small number of parallel tubes in contact with each other, while the other medium flows through the spaces between these contiguous tubes and through the spaces between the outermost of these tubes and a jacket tube of circularly cylindrical shape which surrounds them and contacts those outermost tubes. Heat exchangers of this kind are easy to construct, but they are not satisfactory, for operation with the small temperature differences between the two media required in low temperature systems, because of the wide disparity of rate of flow of the one medium over the cross-section of the complete exchanger.

In the heat exchanger of the invention in contrast, there is provided a plurality of circular tubes of the same cross-section for conduction of the gas at low pressure which are parallel to each other and which touch each other longitudinally, i.e., along elements or generatrices of their circularly cylindrical shape, and these tubes are formed into a nest or bundle enclosed by a jacket tube of polygonal cross-section which touches the outermost tubes of the bundle along a generatrix of each. The spaces of approximately triangular cross-section between the small tubes and between the outermost thereof and the jacket tube serve for passage of the gas at high pressure. Consequently the cross-section for flow of the low pressure gas, i.e., the aggregate of the cross-sections of the small tubes, is greater than the cross-section for flow of the high pressure gas, and moreover the major part of the cross-section for flow of the high pressure gas is made up of the spaces between the individual tubes—as distinguished from the space between the outer tubes of the bundle and the surrounding jacket.

By reason of the form of construction of the exchanger of the invention, there is achieved a nearly uniform mass distribution or flow density among all of the individual

streams across the cross-section of the heat exchanger taken in respect of the heat exchange surfaces, and at the same time there are achieved large heat exchange surfaces and high heat transfer values as will presently be more fully explained.

With reference to its cross-section the heat exchanger of the invention has a relatively long length, for instance the tube length is at least five hundred times the diameter of the individual tubes, relatively high streaming speeds of the media and large heat transfer values being thereby obtained based on the relative small cross-section of the heat exchanger.

The relatively large temperature difference between the two media at the cold end of the exchanger compared to the relatively small temperature difference at the hot end, is specified by the requirements of the process to be carried out in the low temperature system in which the exchanger is especially intended to be used. In the case of a relatively low preliminary cooling temperature (that of the high pressure gas upon entry into the exchanger), there will appear at the cold end of the exchanger a temperature difference which is large compared to that obtainable in a heat exchanger having tubes of lower flow resistance for the high pressure gas. This is a consequence of the relatively large throttling undergone by the high pressure gas in the exchanger, and is consistent with the entropy diagrams of gases of low boiling point. The invention consequently has a number of advantages. The increase in entropy experienced by the high pressure gas in its passage from the input to the exchanger at high pressure through its expansion in the throttling valve and exit from the exchanger at low pressure, which increase in entropy is determined by the throttling losses, is independent of the magnitude of the pressure drop undergone by the high pressure gas in the exchanger. By comparison however with a heat exchanger in which the high pressure gas experiences only a small drop in pressure, the temperature difference at the cold end of the exchanger is in the exchanger of the invention comparatively large in consequence of the heavy throttling. The result is that either for a specified value of the necessary small temperature difference at the hot end, the exchanger can be constructed of smaller length, or else for a given length of the exchanger the temperature difference between the two media at the hot end can be reduced.

Temperature differences accidentally occurring in the intermediate spaces traversed by the partial streams by reason of small irregularities in mass distribution or rate of flow are smoothed out in the exchanger of the invention by reason of the fact that the jacket encloses the tubes and contacts them and by reason of the fact that the tubes touch each other, so that flow of heat can occur transversely of the direction of streaming to dissipate these differences. In a preferred embodiment the invention is characterized by an additional feature according to which for suppression of possible temperature differences among the partial streams passing through the intermediate spaces, the tubes exhibit at least once along their length a constriction in cross-section. This effects a spatial interconnection, intermediate the ends of the exchanger, of all of the inter-tube spaces, and within this interconnection there occurs a mixing or cross-mixing of the streams flowing through those spaces. These mixing spaces can be distributed at various positions along the length of the heat exchanger.

The invention will now be further described in terms of a number of exemplary embodiments with reference to the accompanying drawings wherein:

FIG. 1 is a diagram of a low temperature system such as may be employed for the liquefaction of helium;

FIG. 2 is a view in elevation, partly in section, of a heat exchanger according to the invention;

FIG. 3 is a sectional view taken on the line II—II in FIG. 2 shown however at an enlarged scale; and

FIG. 4 is a further fragmentary view of the heat exchanger of FIG. 2.

In the diagrammatic showing of a low temperature system of FIG. 1, reference character 1 identifies a heat exchanger according to the invention upstream of a throttling valve 2 in which the gas to be cooled or liquefied, e.g., helium, is expanded down to its liquefaction pressure. The gas to be cooled is introduced into the system through the line 3 and is compressed in the compressor 4. This gas, flowing downwardly at the left in FIG. 1, is then cooled in the heat exchangers 5, 6 and 7 by heat exchange with gas at low temperature flowing upwardly at the right in FIG. 1. It is additionally cooled by expansion with performance of external work by the flow of a part of the stream through two expansion turbines 8 and 9, the gas flowing through these turbines also passing through these exchangers 5, 6 and 7. As a result of these operations, the gas is cooled down to a preliminary cooling temperature T_v below its inversion temperature. In the heat exchanger 1 according to the invention the gas at high pressure passes downwardly (in FIG. 1) in heat exchange relation with gas at low temperature obtained as the non-liquefied fraction of the high pressure gas expanded through throttling valve 2 and/or from liquefied gas which has been revaporized, this gas at low temperature which serves to absorb heat being withdrawn from the vapor space of a container 10. By reason of the construction of the exchanger 1 in accordance with the invention, the gas at low pressure emerges from the exchanger 1 at a temperature which is only a fraction of a degree below the pre-cooling temperature T_v . The foregoing references to upward and downward directions of flow are only for explanation of the diagram of FIG. 1; the apparatus of the invention is not limited by or to any such orientations.

The heat exchanger shown in FIG. 2 comprises a pressure resistant exterior or jacket tube 11 having a hexagonal cross-section as indicated in FIG. 3. In the embodiment illustrated, the jacket 11 encloses sixty-one tubes 12 which may be made for example of aluminum or copper. At the ends of the exchanger are provided end pieces 13 and 14 which may advantageously include conical portions joined by a cylinder to which connecting tubes 15 and 16 are provided for the supply and withdrawal of the gas at high pressure. The gas at high pressure to be cooled, in the use of the exchanger described, flows through the intermediate spaces 17 (FIG. 3) between the tubes 12 and through the intermediate spaces 18 between the outermost tubes 12 of the nest or bundle and the surrounding jacket tube 11. The tubes 12 are splayed out in conical fashion within the end vessels 13 and 14 to provide junction or mixing spaces 19 for the intermediate spaces 17 and 18 and to permit flow from and to those spaces 17 and 18 and the supply and withdrawal conduits 15 and 16. The tubes 12, which in the non-limitative exemplary use of the invention described are traversed by the gas at low pressure in the opposite direction from that in which the spaces 17 and 18 are traversed, open at the opposite ends of the exchanger through isolating walls, of which one is shown at 21, into a collection space of which one is indicated at the upper end of the exchanger in FIG. 2 by the reference character 20. At each end of the exchanger the wall 21 provides a gas-tight separation between the spaces 19 and 20. Connections 22 and 23 are provided to the tube spaces 20 for supply and withdrawal of low pressure gas to and from the exchanger.

As has hereinabove already been mentioned, according to a further feature of the invention, a constriction is provided in the tubes 12 at least one point located between the ends of the jacket tube. This is indicated in FIG. 4. FIG. 4 shows three of the inner tubes 12 all having a constriction 24 at the same position lengthwise thereof. At the location of these constrictions there is thus provided an interconnection, as indicated at 25, among all of the intermediate spaces 17 which assists in suppressing the

development of temperature differences among the streams of gas flowing through these spaces 17.

The ends of the tubes 12 may likewise be provided with constrictions inside the spaces 19, i.e., prior to their passage through the separating walls 20 at the upper and lower ends of the exchanger. In such a construction therefore the splaying out of the tubes illustrated at the upper end of FIG. 2 may be dispensed with.

In a preferred form thereof the heat exchanger of the invention possesses a hexagonal cross-section as indicated in FIG. 3. With such a hexagonal cross-section and a bundle of thirty-seven of the tubes 12 for the low pressure gas, the cross-section of flow for the high pressure gas provided in the spaces 17 between adjacent tubes 12 will be large compared to that provided by the spaces 18 between the outer limits of the bundle and the jacket 11. If desired, the intermediate spaces 18 between the tubes 12 and the surrounding shroud can be further reduced by the insertion of blocking elements such as longitudinally extending wires.

The larger the number of tubes 12 for a given total cross-section, the larger will be the preponderance of the cross-sectional area for flow of high pressure gas provided by the inter-tube spaces 17 over that provided by the spaces 18 and hence the more effective will be the heat exchange for a given length of the exchanger. By reason of the relatively large length of the exchanger, it may be desirable to form it into a helical or other curved pattern.

While the heat exchanger of the invention has been described in terms of its application to heat exchange between a gas at high pressure and a low pressure gas throttled to a particular pressure, the invention finds application also in cases where for example the high pressure gas is throttled at two valves downstream of the heat exchanger. In such a case the partial stream of gas at low pressure obtained after the first throttling passes through one fraction of the heat exchanger tubes whereas that obtained from the second throttling pass through the others.

While the invention has been described hereinabove in terms of a number of presently preferred embodiments, the invention itself is not limited to those embodiments but rather comprises all modifications on and departures from those embodiments properly falling within the spirit and scope of the appended claims.

We claim:

1. Low temperature apparatus for the cooling or liquefaction of a gas of low boiling point such as hydrogen or helium in which the gas is compressed to high pressure, then cooled below its inversion temperature and then cooled by heat exchange with a low temperature gas flowing in countercurrent flow therewith through a heat exchanger prior to expansion in a throttling valve, said apparatus comprising a heat exchanger including a plurality of tubes of circular cross-section through which the low pressure gas flows, the tubes being arranged parallel to each other and in contact with each other in a honeycomb bundle of polygonal cross-section with spaces of substantially triangular cross-section between the adjacent tubes of the bundle, said exchanger further comprising a jacket having a polygonal cross-section surrounding the bundle and contacting the outer tubes thereof to define additional spaces of substantially triangular cross-section between said jacket and the outermost tubes of the bundle, said tubes having a constriction at a common location lengthwise thereof within said jacket, the aggregate cross-section of the interior of said tubes being larger than the aggregate cross-section of the spaces between said tubes plus the spaces between said tubes and jacket, and the aggregate of the cross-section of the spaces between said tubes being larger than the aggregate of the cross-section of the spaces between said tubes and jacket.
2. Apparatus according to claim 1 wherein the cross-section of the jacket is hexagonal.

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