March 6, 1956 A. LATHAM, JR 2,737,032

REFRIGERATION SYSTEM AND METHOD

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Fig. 1

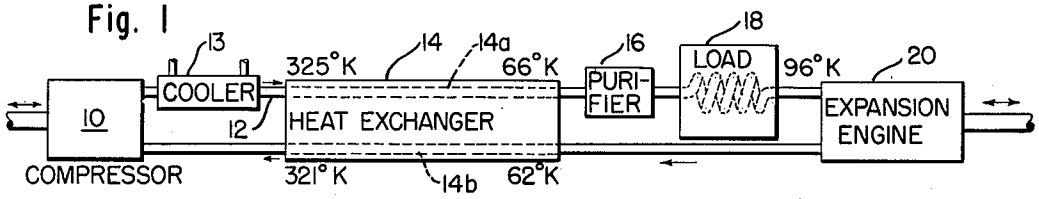


Fig. 2

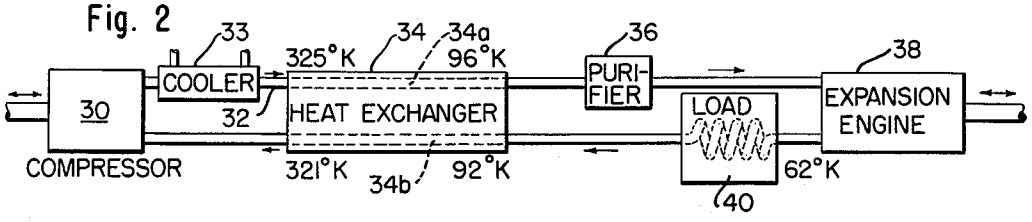


Fig. 3

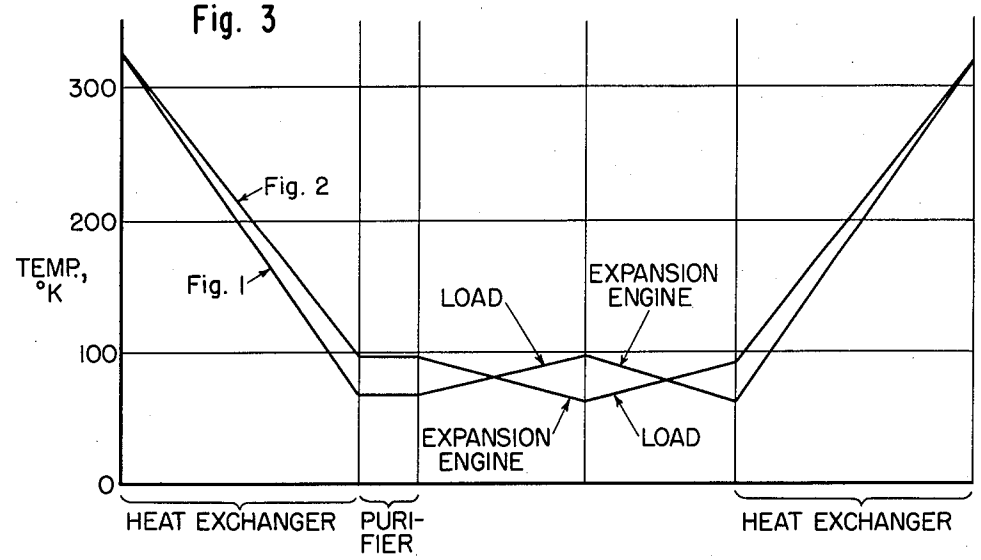
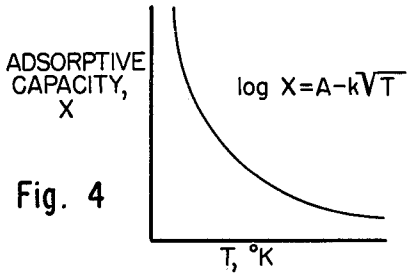


Fig. 4



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REFRIGERATION SYSTEM AND METHOD

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The present invention relates to refrigeration systems and is directed particularly to low temperature refrigeration systems employing the expansion of compressed refrigerant gases.

Where extremely low temperatures are to be produced by mechanical refrigeration, it is generally desirable to employ in the refrigeration cycle one or more gas expansion steps wherein external work is performed by the expanding gas. Such expansions are generally carried out in expansion engines which include a member movable by the expansion of compressed gas in a closed chamber, and means operatively connected with the movable member for transmitting work from the engine to an appropriate load. The extremely low temperatures at which these engines are run precludes the use in them of lubricants. Accordingly, when the compressed gas is expanded in such an engine, it is extremely important that it be as free as possible from contaminating materials, especially solids and materials condensable to solids. In refrigeration systems wherein the gas is expanded in a throttle valve, it is also important that the expanding gas be as free as possible from such impurities and the present invention may be used in systems wherein expansion is performed in a throttle valve. To remove impurities from the gas, it is the common practice to pass the gas through a purifier prior to expansion. In the purifier the gas is passed in contact with the surface of an adsorbent. It is well known that the adsorptive capacity of adsorbents such as charcoal which are used to purify gases increases as the temperature of the gas decreases. Moreover, as the temperature of the gas decreases, not only are some impurities adsorbed to a greater degree, but other impurities which can be adsorbed only slightly at higher temperatures are readily removed. In some cases the condensation of some impurities to the solid form may be effected if the temperature in the purifier is sufficiently low, so that they may be filtered out mechanically.

It is a primary object of this invention to enhance the efficiency of the purification of the refrigerant gas prior to the expansion stage. A further object is to cool the refrigerant gas prior to its expansion to a temperature only slightly higher than the temperature attained during expansion. This is desirable because it provides a maximum assurance against the condensation of contaminating materials during the expansion and accompanying drop of temperature. Other objects will become apparent from the following disclosure.

In general, the objects of this invention are realized by passing the cooled, compressed refrigerant gas into the load (the source of heat to be removed by refrigeration) before expanding it, then expanding the gas and passing the expanded cold gas into countercurrent out-of-contact heat exchange relation with the compressed gas prior to its passage into the load. Thus, in effect, the load is cooled by a secondary refrigerant, the compressed gas, which has first been cooled by the primary refrigerant, the expanded gas. By cooling the gas to refrigeration temperature, then passing it through the load before expanding it, the temperature of the gas is first raised during its passage through the load, then cooled by expansion to a temperature only low enough to be effective to cool the compressed gas to refrigeration temperature in a heat exchanger. A purifier may then be situated in the system between the heat exchanger and the load and it will operate at a temperature very near the low temperature produced by the expansion to provide maximum purification.

By comparison, a conventional system wherein the gas is expanded prior to its passage through the load, requires a purifier between the heat exchanger and the expansion engine, at a point in the system where the temperature is above the entire temperature range of the expanding gas.

The present invention will be better understood from the following detailed description of a preferred embodiment thereof and a comparison of the system of the present invention with a conventional refrigeration system. Reference is made to the drawings in which:

Figure 1 is a diagrammatic drawing of a refrigeration system embodying the present invention,

Figure 2 is a diagrammatic drawing of a conventional refrigeration system,

Figure 3 is a graph showing the temperature variations through the systems shown in Figs. 1 and 2, and

Figure 4 is a graph showing the variation of the adsorptive capacity of a typical adsorbent with the temperature.

Referring now to Figure 1, the system of the present invention includes a compressor **10** which discharges compressed gas into a conduit **12**. A cooler **13** surrounds the conduit **12** to remove the heat of compression from the compressed gas. The conduit **12** leads into one channel **14***a* of a double channel heat exchanger **14** which in turn leads into a purifier **16**. The purifier **16** communicates with the refigerating load **18** (the source of heat to be removed by refrigeration) and the load **18** communicates with the inlet side of the expansion engine **20**, which may be of either the turbine or reciprocating piston type. The outlet side of the expansion engine **20** communicates with the other channel **14***b* of the heat exchanger **14** which in turn, leads back to the low pressure side of the compressor **10**.

The heat exchanger is of conventional design and may consist of two separate channels thermally bonded together so that heat may be readily transferred from a relatively warm fluid in one channel to a relatively cold fluid in the other channel. The purifier **16** is also of conventional design and may consist of a container containing an adsorbent such as charcoal or silica gel and means for passing the compressed gas in contact with the adsorbent.

In the operation of this embodiment of the present invention, a refrigerant gas such as helium is compressed in the compressor **10** and then partially cooled in the cooler **13**. In a typical operation, the gas is compressed to 230 p. s. i. a. and then cooled to 325° K. The gas is then passed through the heat exchanger **14** and there brought into heat exchange relation with the expanded gas from the expansion engine, and cooled to refrigeration temperature of 66° K. The cold gas then passes through the purifier **16** and thereafter through the load **18** wherein its temperature is raised to 96° K. by the heat removed from the load. The gas then enters the expansion engine **20** and is expanded with the performance of external work to a pressure of 57.5 p. s. i. a. to reduce its temperature to 62° K. The expanded gas then passes through the heat exchanger in a direction countercurrent to that of the compressed gas thereby to cool the compressed gas while becoming heated to 321° K.

The warm, expanded gas then returns to the compressor **10** where it is recompressed and returned to the refrigeration cycle.

To emphasize the advantages of the system provided by the present invention, a description of a corresponding conventional refrigeration system will now be given. Such a system is shown in Fig. 2. It consists of a compressor **30** which discharges into a conduit **32** which may be surrounded by a cooler **33**. The conduit **32** leads into one channel **34***a* of a heat exchanger **34**. This channel of the heat exchanger **34** then communicates with a purifier **36** which in turn communicates with the intake side of an expansion engine **38**. The outlet of the expansion engine **38** leads through the load **40** which in turn, communicates with the other channel **34***b* of the heat exchanger **34**. This channel of the heat exchanger **34** then leads to the low pressure intake of the compressor **30**.

In a comparable operation of this system, the gas is compressed to 230 p. s. i. a. in the compressor **30** and then cooled to 325° K. in the cooler **33**. In the heat exchanger **34**, the compressed gas is cooled to only 96° K. and passes at this temperature through the purifier. The gas is then expanded in the expansion engine **38** to a pressure of 57.5 p. s. i. a. and a temperature of 62° K. The cold, expanded gas then passes through the load **40** wherein its temperature is raised to 92° K. The gas thereafter passes back through the heat exchanger wherein it cools the compressed gas and is warmed to 321° K., and then returns to the compressor **30** to be re-compressed and returned to the cycle. The system of Fig. 2 is in general similar to that described in the Collins Patent No. 2,458,894, and the various parts shown in both Figs. 1 and 2 may be of the construction of corresponding parts of the Collins patent.

A comparsion of the refrigeration system of the present invention with a conventional refrigeration system is shown graphically in Fig. 3 which shows the temperature of the gas at the various stages in the cycles of the two systems. In the conventional system, which is represented by the line marked as Fig. 2, the gas is compressed and cooled to a temperature from which is may be expanded to the desired refrigeration temperature. It is at this relatively high temperature that the gas is passed through the purifier. During the expansion stage which follows, the temperature of the gas is lowered further with the result that impurities which were not removed by the purifier may condense in the engine and cause it to foul. The danger of fouling is minimized in the system of the present invention, which is represented by the line marked Fig. 1 of the graph of Fig. 3. In this system, the gas is passed through the purifier at a temperature appreciably lower than the temperature at which it enters the expansion engine. This minimizes the danger that the cooling of the gas which results from its expansion, will result in the condensation of impurities which were not removed by the purifier.

The advantages afforded in the system of this invention by passing gas through the purifier at a temperature near the low point of the expansion, includes not only the maximum removal of condensable material, but also the maximum removal of all impurities which may be adsorbed. This latter effect is attained because the adsorptive capacity of typical adsorbents such as charcoal or silica gel, is greatly enhanced by decreases in temperature. The adsorptive capacity of charcoal as a function of temperature may be represented by the formula:

$$\text{Log } X = A - K\sqrt{T}$$

where X represents the adsorptive capacity in grams adsorbed per gram of charcoal, A represents a constant, K represents a constant, and T represents the temperature in absolute units.

A plot of this formula is shown in Fig. 4. It will be seen from this plot, that at the extremely low temperatures encountered in refrigeration systems of the type with which this invention is concerned, a substantial increase in the adsorptive capacity results with even relatively minor decreases in the temperature of the gas.

The foregoing description is presented as illustrative of the refrigeration system of this invention. The temperatures and pressures described with respect to this system, represent typical conditions encountered in systems of this type, and they should not be construed in any limiting sense. In this respect, it will be understood that the expansion ratio may be varied considerably as may be the rate that heat is supplied by the load, and that, accordingly, the temperatures throughout the system may be varied within wide limits. Also material to the conditions that exist in this system, is the efficiency of the heat exchanger, which is desirably constructed to provide a maximum of heat interchange, so that a minimum temperature differential between the two streams may be maintained. Accordingly, it is contemplated that many modifications of the system described above will be apparent to those skilled in the art, and that such modifications may be made without departing from the scope of this invention.

Typical applications of the system of the present invention described above include the rectification of air to produce liquid oxygen wherein the load consists of a nitrogen condenser for the production of reflux such as described in Patent No. 2,458,894. This system may also be used to cool storage vessels for liquefied gases wherein the load consists of a cooling element in thermal contact with the stored liquefied gases. In general, the system of this invention may be used for the production of low temperatures between the boiling points at atmospheric pressures of helium and oxygen, or higher if desired.

Having thus disclosed my invention, and described in detail a preferred embodiment thereof, I desire to claim and secure by Letters Patent:

1. A low temperature compressed gas refrigeration system comprising a heat exchanger containing a compressed gas channel for conducting a compressed gas through the exchanger and an expanded gas channel thermally bonded to the compressed gas channel for conducting an expanded gas through the exchanger, a refrigeration load communicating with the compressed gas channel, means for expanding the compressed gas through a temperature decrease larger than the temperature increase through the load, means for conveying said compressed gas after its passage through the load to the expansion means, and means for conveying said expanded gas from the expansion means to the expanded gas channel of the exchanger.

2. A low temperature compressed gas refrigeration system comprising a heat exchanger containing a compressed gas channel for conducting a compressed gas through the exchanger and an expanded gas channel thermally bonded to the compressed gas channel for conducting an expanded gas through the exchanger, a gas purifier communicating with the compressed gas channel, a refrigeration load, means for conveying said compressed gas after its passage through the purifier to the load, means for expanding said compressed gas to the lowest temperature point in the system, means for conveying said compressed gas after its passage through the load to the expansion means, and means for conveying said expanded gas from the expansion means to the expanded gas channel of the exchanger.

3. A low temperature compressed gas refrigeration system comprising a compressor, a cooler adapted to remove the heat of compression from a compressed gas, means for conveying the compressed gas from the compressor to the cooler, a heat exchanger containing a compressed gas channel for conducting a compressed gas through the exchanger and an expanded gas channel thermally bonded to the compressed gas channel for conducting an expanded gas through the heat exchanger,

means for conveying the compressed gas from the cooler to the compressed gas channel of the exchanger, a gas purifier, means for conveying said compressed gas after its passage through the exchanger to the purifier, a refrigeration load, means for conveying said compressed gas after its passage through the purifier to the load, an expansion engine for expanding said compressed gas with the performance of external work to the lowest temperature point in the system, means for conveying said compressed gas after its passage through the load to the expansion engine, means for conveying said expanded gas from the expansion engine to the end of the expanded gas channel of the exchanger corresponding to the outlet end of the compressed gas channel, and means for conveying said expanded gas from the end of the expanded gas channel of the exchanger corresponding to the inlet end of the compressed gas channel to the compressor.

4. A method of producing low temperature refrigeration comprising cooling a compressed gas to refrigeration temperature by passing it in out-of-contact heat exchange relation with a stream of the same gas after expansion, passing the cooled compressed gas through a purifier, passing the cooled compressed gas from the purifier through a refrigeration load, expanding the compressed gas after its passage through the load to a temperature below refrigeration temperature, and passing the expanded gas in out-of-contact heat exchange relation with the compressed gas.

5. A method of producing low temperature refrigeration comprising compressing a gas, removing the heat of compression from the compressed gas, cooling the compressed gas to refrigeration temperature by passing it in

countercurrent out-of-contact heat exchange relation with a stream of the same gas after expansion, passing the cooled compressed gas through a purifier, passing the cooled compressed gas from the purifier through a refrigeration load, expanding the compressed gas with the performance of external work after its passage through the load to a temperature below refrigeration temperature, and passing the expanded gas in countercurrent out-of-contact heat exchange relation with the compressed gas.

6. A low temperature compressed gas refrigeration system comprising a heat exchanger having a compressed gas channel and an expanded gas channel in heat-exchange relation, a purifier, a refrigeration load, expansion means, means for conducting a compressed gas through the compressed gas channel to be cooled to a temperature only slightly higher than that attained in the expansion means, means for conducting the gas from said compressed gas channel successively through the purifier, the load and the expansion means to the lowest temperature point in the system, and means for conveying the expanded gas from the expansion means to the expanded gas channel of the heat exchanger.

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