

June 27, 1967

S. ERGENC

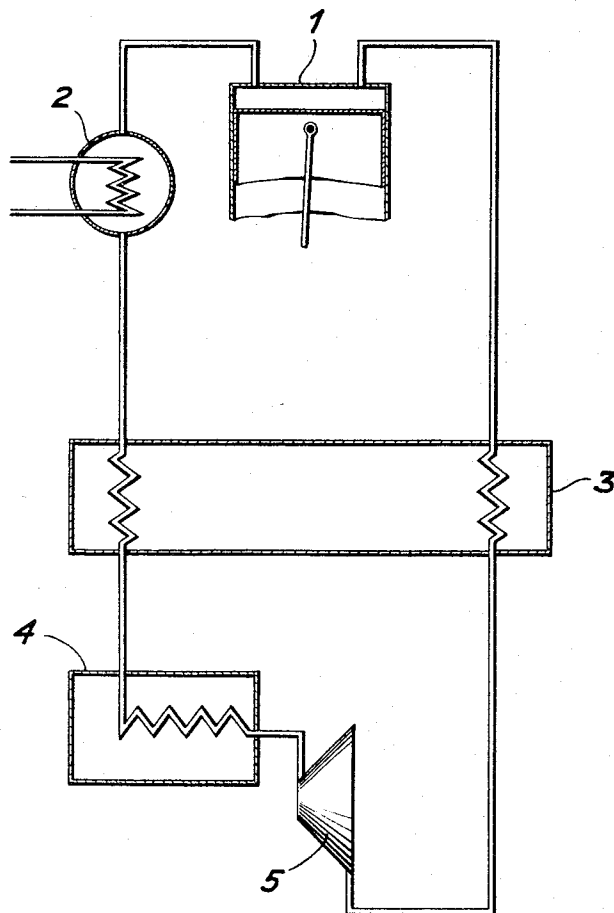
3,327,495

GAS COOLING SYSTEM

Filed Dec. 10, 1965

5 Sheets-Sheet 1

Fig. 1



Inventor:

Sahabettin Ergenc

BY *Pennie, Edmonds,*
Morton, Taylor and Adams
ATTORNEYS

June 27, 1967

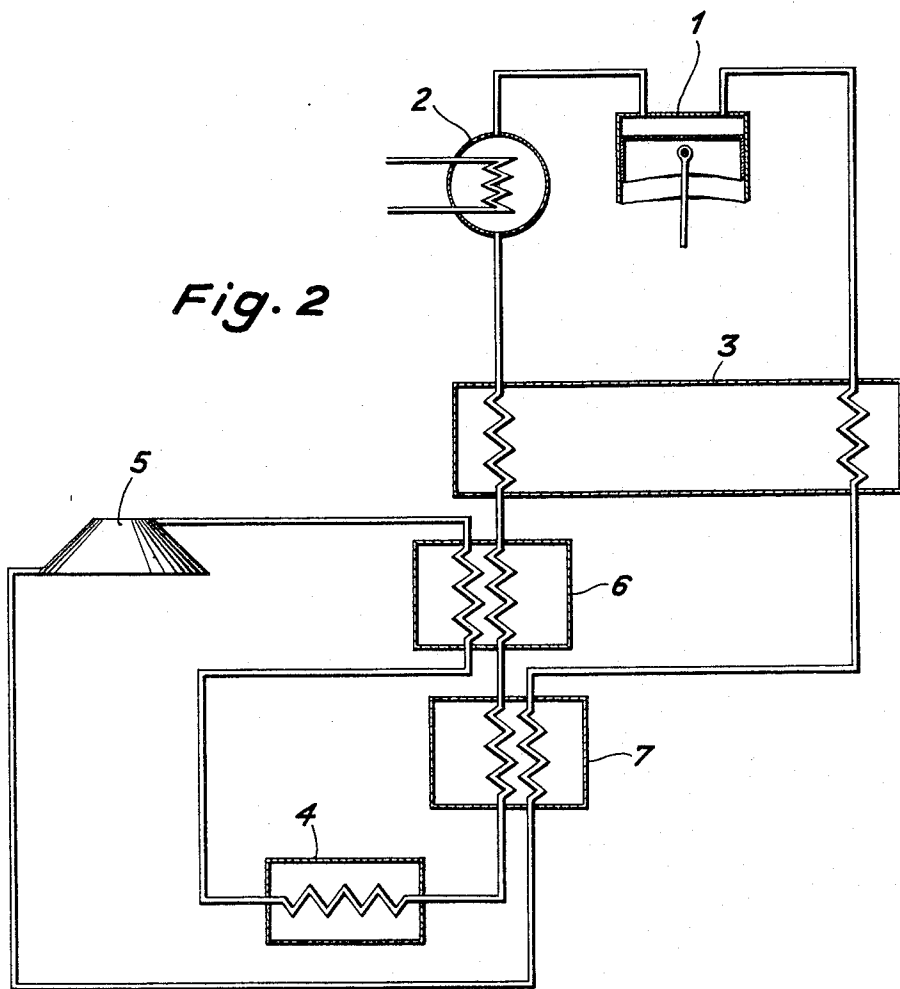
S. ERGENC

3,327,495

GAS COOLING SYSTEM

Filed Dec. 10, 1965

5 Sheets-Sheet 2



Inventor:

Sahabettin Ergenc

BY *Gennie Edmonds,*

Morton, Taylor and Adams

ATTORNEYS

Filed Dec. 10, 1965

GAS COOLING SYSTEM

5 Sheets-Sheet 3



Inventor:
Sahabettin Ergenc
BY *Pennie, Edmonds,*
Morton, Taylor and Adams
ATTORNEYS

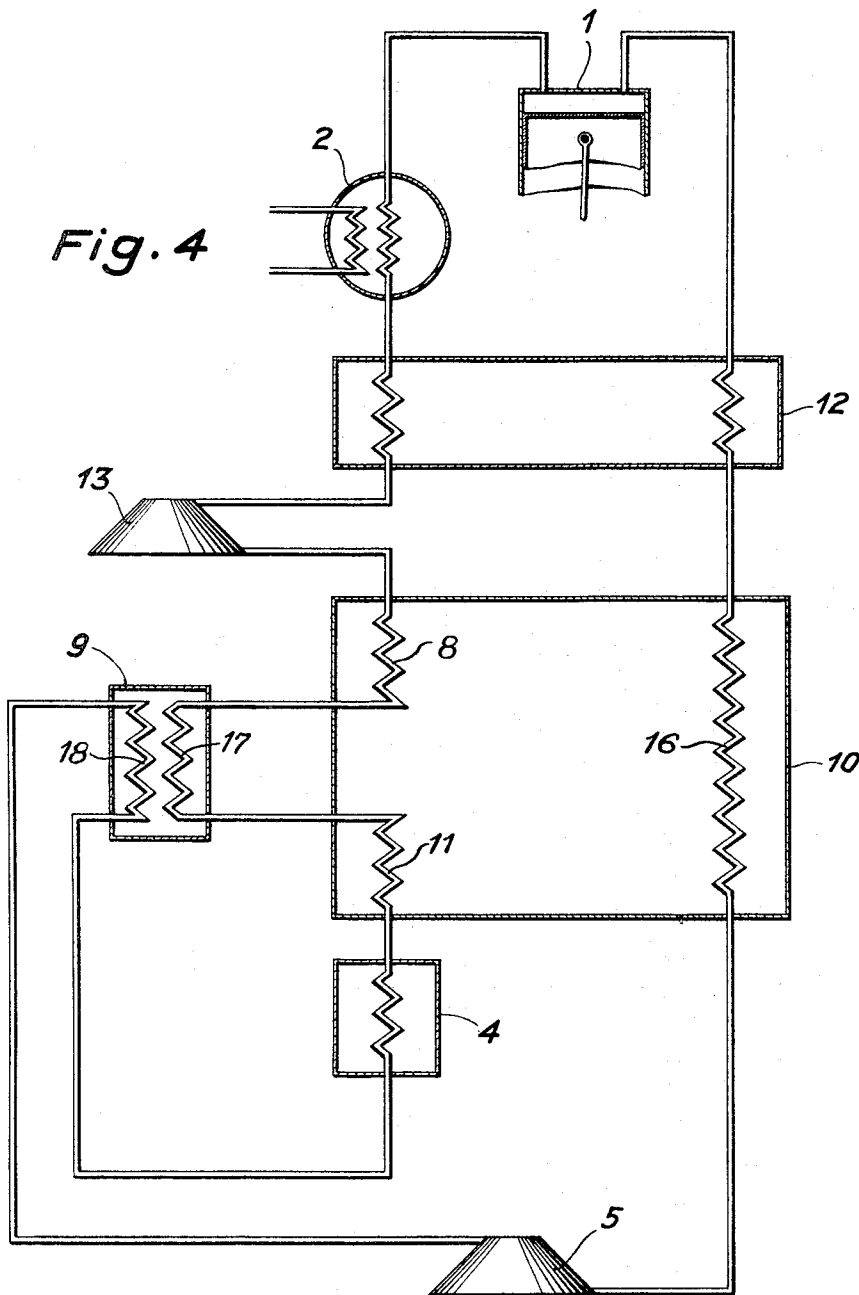
June 27, 1967

S. ERGENC
GAS COOLING SYSTEM

3,327,495

Filed Dec. 10, 1965

5 Sheets-Sheet 4



Inventor:

Sahabettin Ergenc
BY *Pennie, Edmunds,*
Morton, Taylor and Adams
ATTORNEYS

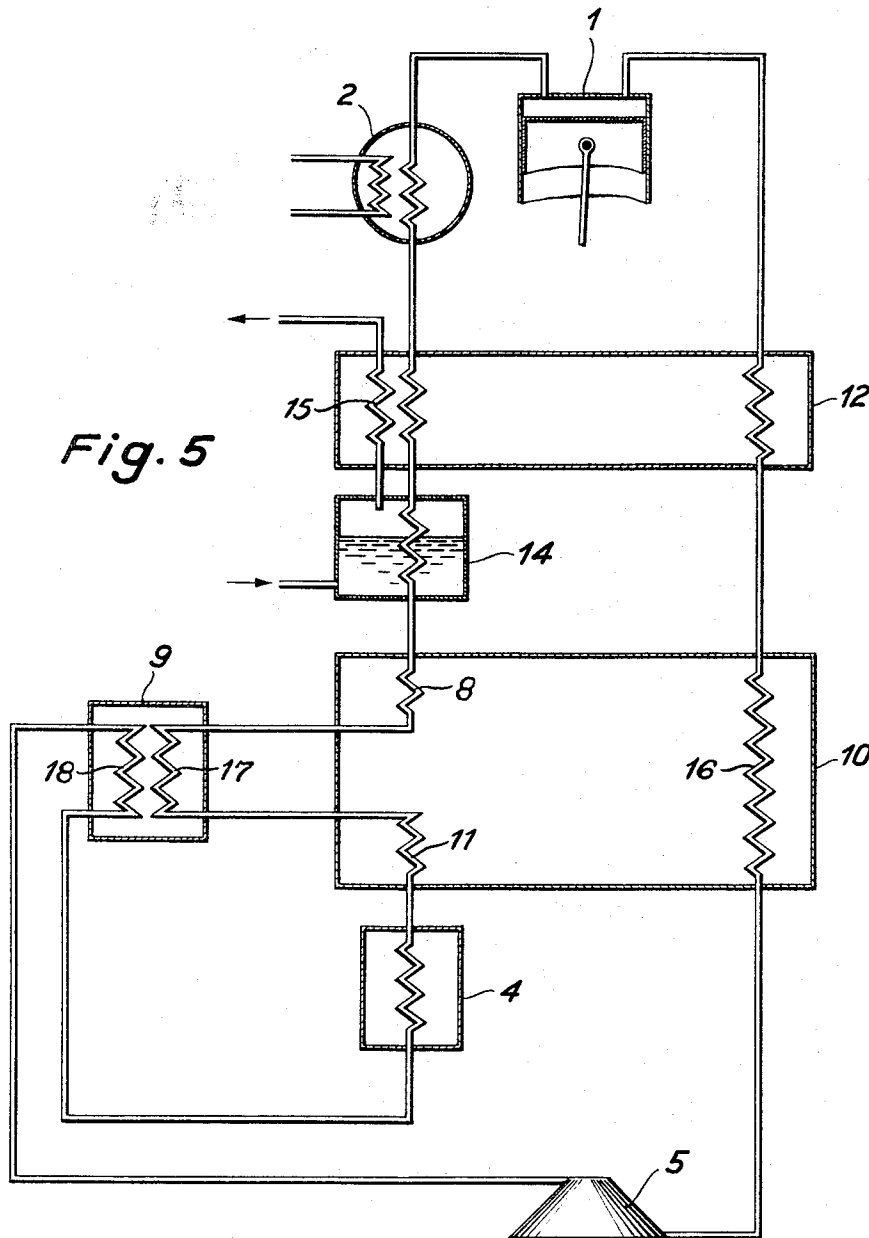
June 27, 1967

S. ERGENC
GAS COOLING SYSTEM

3,327,495

Filed Dec. 10, 1965

5 Sheets-Sheet 5



Inventor:
Sahabettin Ergenc
BY *Pennie, Edmonds,*
Morton, Taylor and Adams
ATTORNEYS

1

3,327,495

GAS COOLING SYSTEM

Sahabettin Ergenc, Zollikoberg, Zurich, Switzerland, assignor to Sulzer Brothers Limited, Winterthur, Switzerland, a Swiss company

Filed Dec. 10, 1965, Ser. No. 513,003

Claims priority, application Switzerland, Dec. 15, 1964, 16,187/64

2 Claims. (Cl. 62—401)

The present invention pertains to a gas cooling or refrigeration system in whose coolant circuit there circulates as the refrigerant or cooling medium a gas of low liquefaction temperature which is difficult to liquefy. This gas is compressed and is thereafter cooled, partly by heat exchange and partly by expansion with performance of external work, and it extracts heat by heat exchange from a cooling load, i.e. from a body or system to be maintained at low temperature. The elements of the cooling system of the invention comprise essentially a compressor, one or more heat exchangers, and at least one expansion machine for the expansion of gas. The expansion machine may be of either the turbine or piston type. The gases which are difficult to liquefy and which are useful in the invention are those which under normal conditions, i.e. at 0° C. and 1 atmosphere absolute pressure, behave substantially like ideal gases and which therefore substantially conform under those conditions to the ideal gas laws. Suitable gases include, for example, hydrogen, oxygen, and nitrogen, and also the noble gases such as helium, neon, etc.

In prior gas cooling systems employing as refrigerant a gas of this type it has been customary to constitute the cooling circuit in the following manner: After compression of the cooling medium gas to a high pressure and subsequent extraction therefrom of the heat of compression, the gas under high pressure is cooled by heat exchange with gas at low pressure which has been expanded to such low pressure with the performance of external work. The gas so preliminarily cooled is further cooled by expansion, with performance of external work, in an expansion machine, and is thereafter raised in temperature by absorption of heat in a load, the heat so absorbed representing the refrigeration effected. Lastly, the cooling medium gas is further heated substantially to ambient temperature, by heat exchange in the process of chilling other cooling medium gas in the cycle which has been compressed to high pressure. The gas so raised to room temperature is then once again compressed by the compressor, to repeat the cycle.

In many applications the cooling load, which takes the form of a heat exchanger, must be made small for reasons of space economy. Consequently, the cooling medium must be delivered to that load through one or more conduits of long length and small cross-section. Additionally it may be necessary, in order to effect good heat exchange, to provide a large heat exchange surface in the form of a tube or circulating channel having a long length and a small cross-section through which the cooling medium will flow for absorption of heat from the load. Such a construction for the load heat exchanger produces however a large resistance to flow, so that large pressure drops occur in that exchanger. To overcome that drop in pressure, the ratio of output to input pressures at the compressor must be raised, which in turn signifies increased energy consumption by the compressor and may increase the constructional cost of the apparatus.

It is an object of the invention to reduce the supplementary power requirements in a gas cooling or refrigeration system. According to the invention, such a system is so constructed that the cooling medium, after passing

2

through a cooling load, is cooled to the lowest temperature of its cycle by expansion with performance of external work in at least one expansion machine.

A gas cooling system according to the invention can be employed, for example, for the cooling of electromagnets. Since the electrical resistance of a conductor declines with falling temperature, it has been proposed to cool the energizing coils of electro-magnets down into the region of extremely low temperatures. The invention makes it possible to cool the coils of such magnets in an advantageous manner by constructing the conductors as hollow tubes and by circulating through those tubes a gas cooled to very low temperature. Since the cross-section of these tubes is small and since the path length there-through is large, the result is a large pressure drop.

Assuming isothermal compression, the work L which the compressor must perform to overcome the pressure drop in the cooling load is given by the equation:

$$L = GRT \log_e \frac{P_1}{P_2}$$

in which G represents the quantity of circulating cooling medium, R its gas constant, T the absolute temperature, P_1 the inlet pressure into the coolant load and P_2 the pressure at the outlet thereof. In a cooling system according to the invention, by comparison with a conventional system in which the expansion of the cooling medium with performance of external work to provide the cooling capacity absorbed in the load takes place upstream of that load, this work can be reduced by at least a factor approximately equal to the square of the pressure ratio of the expansion machine, i.e. the ratio of inlet to outlet pressures thereto. This fact will be confirmed in terms of a numerical example in the detailed description of the invention which is to follow.

Since the invention makes it possible to achieve this substantial reduction in compressor power requirements, the somewhat smaller cooling effect produced by the expansion machine, which operates in the invention at a somewhat lower mean temperature than in the conventional systems above described, is of little consequence. The amount by which the mean temperature of the expansion machine is lowered in the system of the invention, by comparison with the prior art systems, corresponds approximately to the temperature difference at the cold end of the exchanger into which the expanded cooling medium enters. The pressure ratio at the work-performing expansion effected after exit of the cooling medium from the coolant load, i.e. the ratio of pressure before to pressure after that expansion, must be raised in the system of the invention, in order to compensate for the slightly reduced cooling effect on the gas of a given expansion at lowered temperature, but this results in an increase in the required compressor power which is far smaller than the reduction therein achieved by the invention.

According to another feature of the invention however, the means temperature of the cooling medium during its expansion with performance of external work can be raised (with beneficial results on the cooling effect of that expansion) by passing the cooling medium, before its entry into the load, in heat exchange relation successively with cooling medium passing from the load to the expansion machine and with expanded cooling medium passing from the expansion machine toward the compressor. With this arrangement, each of these heat exchange steps is operative to lower the temperature of the medium flowing toward the load.

The expansion machines employed may advantageously be turbines. In a cooling system according to the invention this has the advantage that the turbine operates in a range of lower pressures by comparison with customary

practice and hence has a higher throughput. The efficiency is therefore improved because the turbine is larger.

The invention will now further be described in terms of a number of exemplary embodiments by reference to the accompanying drawings wherein FIG. 1 shows one embodiment of a cooling system according to the invention and FIGS. 2-5 show variant systems also according to the invention.

Referring to FIG. 1, the cooling system of the invention, which may employ helium as the cooling medium, comprises a piston-type compressor 1, a cooler 2 for dissipation or extraction of the heat of compression, a heat exchanger 3, a heat exchanger 4 for absorption of heat from the load to be cooled, and one or more expansion turbines 5 which is plural may comprise several turbines in series.

The mode of operation of the system of FIG. 1 is as follows: The cooling medium, fed into the system through a conduit not shown, is compressed in compressor 1. The heat of compression is removed from the cooling medium in a cooler 2, which exhausts heat to a sink not shown. The cooling medium is then lowered in temperature to the level desired for its introduction into the load (shown as a heat exchanger 4), by heat exchange in the heat exchanger 3, where it flows countercurrent with cooling medium at low pressure and temperature discharged from the expansion turbine 5 downstream of load 4. In passing through the load 4 the cooling medium effects the desired cooling, e.g. by absorbing heat from a material in that load, and is thereby raised in temperature. The cooling medium is then expanded in the expansion turbine 5. In the embodiment shown this turbine serves for generation of the cooling capacity employed in the load, and also to cover the thermodynamic losses in the heat exchanger 3. In its expansion in the turbine 5 the cooling medium is cooled down to the lowest temperature in its complete circuit. From turbine 5 the cooling medium flows into the heat exchanger 3 where it is warmed, extracting heat from the medium flowing from cooler 2 toward load 4, and flows thence up to the suction side of the compressor.

For reduction of the thermodynamic losses there may be advantageously employed, in place of a single heat exchanger 3, two exchangers in series. In such a case, the exchanger immediately upstream of the cooling load, i.e. nearer the load 4, will have for both of its countercurrent flow passages or systems smaller flow cross-sections than will the exchanger farther from that load, and which exchanger operates in a higher range of temperatures.

To show the advantages and achievements of the invention, the following numerical example may be considered. Take for comparison the system of FIG. 1 and a gas cooling system of the prior art having an expansion machine positioned upstream of the cooling load (i.e. between the compressor and the load), and in which the cooling medium flows directly from the cooling load through heat exchangers to the inlet side of the compressor. It will be assumed that in both cases the same quantity of gas G flows in the circuit. It has already been indicated that the supplementary isothermal compressor power necessary to overcome the resistance to flow in the load is given by the equation:

$$L = GRT \log_e \frac{P_1}{P_2}$$

Computing first the quantity L for the system of the prior art, let it be assumed that the cooling medium is reduced from 6 to 3 atmospheres pressure absolute in an expansion turbine upstream of the load. The medium thus reduced to 3 atmospheres is to flow immediately thereafter through a load in which a pressure drop of 1 atmosphere occurs so that the gas will emerge from the load at a pressure of 2 atmospheres absolute, whence it flows through a heat exchanger back to the suction side

of the compressor. If these values are set into the energy equation previously given, then one obtains:

$$L = GRT \log_e \frac{3}{2} = 0.405 GRT$$

If for a computation of the quantity L in the system of the invention according to FIG. 1 one departs from the same assumptions, namely the same quantity G of circulating gas, the same minimum pressure of 2 atmospheres absolute and the same pressure ratio of 2 for the inlet and outlet pressures of the turbine, then one obtains as an inlet pressure to the turbine 5 a pressure of approximately 4 atmospheres.

As is known, the flow resistance is described by the relation

$$\Delta P \sim \frac{1}{P}$$

Consequently, one obtains a pressure drop ΔP of 0.5 atmosphere in the load 4 and hence an inlet pressure of 4.5 atmospheres for the cooling medium at the upstream end of the load. If these values are set into the power expression L , one obtains:

$$L = GRT \log_e \frac{4.5}{4} = 0.118 GRT$$

The additional work to be done by the compressor in overcoming pressure drop of the working fluid in its passage through the load is consequently smaller, in a system according to FIG. 1, by factor of about 405/118 or 3.45. Since the numerical example under consideration departed from the assumption of a pressure ratio of 2 for the expansion turbine, the saving in compression energy amounts substantially to the square of the pressure ratio in the expansion machine. A more exact computation will show that the saving in compression energy is even greater.

In the embodiment of the invention illustrated in FIG. 2, corresponding elements of structure bear the same reference characters. The system of FIG. 2 includes additional heat exchangers 6 and 7 in the flow circuit of the working fluid. In the system of FIG. 2, the gaseous working fluid, which again may be helium for example, after cooling in the exchanger 3 and before passing through the load 4, is cooled by heat exchange with gaseous medium emerging from the load and before expansion of that gas. This heat exchange takes place in the exchanger 6. The gaseous cooling medium or working fluid flowing toward the load is then further cooled in exchanger 7 with a medium which has been expanded in the turbine 5. By reason of this construction, the average temperature of the expansion turbine 5 is somewhat raised so that with the same pressure ratio on that turbine, the cooling effect produced by the turbine is greater in FIG. 2 than in FIG. 1. Advantageously, the cross-sections of the conduits for the cooling medium are larger in the heat exchanger 6 than in the heat exchanger 7.

FIG. 3 shows for essentially the same mode of operation a variant on the construction of FIG. 2. Here in place of the exchangers 3 and 7 of FIG. 2 there is shown a single heat exchanger 10. After the cooling medium at high pressure is cooled in coil 8 of exchanger 10 by heat exchange with gas at low pressure in coil 16 thereof returning from turbine 5 to the compressor, the medium is passed through a heat exchanger 9 corresponding to the exchanger 6 of FIG. 2. In this exchanger 9 it flows countercurrent to the cooling medium emerging from the load 4. Thereafter the cooling medium returns to the heat exchanger 10 for further cooling in coil 11 thereof (by heat exchange with coil 16) to the desired inlet temperature into the load.

FIGS. 4 and 5 show embodiments substantially conforming to that of FIG. 3. In these, to cover the thermodynamic losses in the heat exchanger 12 downstream of the compressor, there are provided an expansion turbine 13 (FIG. 4) and a cooler 14 (FIG. 5) respectively. In the cooler 14 a liquid coolant such as nitrogen may be employed, if the circulating cooling medium is helium or

5

hydrogen, and provided the temperature of the load 4 is lower than the temperature of liquid nitrogen. In the heat exchange with gas at high pressure occurring in cooler 14, the noncirculating coolant is partly vaporized and the vapor so produced is conducted through coil 15 in order to cool the gas at high pressure in the heat exchanger 12, flowing from cooler 2 towards the load, before being removed from the system.

For heat insulation of the low temperature elements of the system, they may be enclosed in a high-vacuum enclosure, exhausted for example to some 10^{-6} mm. Hg.

As already stated therefore, it is conventional in a gas cooling system to effect an expansion of a gaseous working fluid, with performance of external work, in order to lower the temperature of the gas so that it may abstract heat from a load, this expansion and consequent cooling of the working fluid taking place upstream of the load at a location between the compressor and the load. In accordance with the present invention instead, this expansion is effected downstream of the load, between the load and the compressor in the sense of flow of the working fluid around the cycle, and the working fluid chilled by this expansion is employed as the cooling agent in a heat exchanger to cool working fluid which has been compressed (and which has been freed of its heat of compression), prior to entry of such working fluid into the load.

The invention thus provides a gas cooling system, i.e. a cooling or refrigerating system, in which the working fluid is at all points of its cycle in the gaseous phase. The gas cooling system of the invention, as shown for example in FIG. 1, comprises a compressor 1, a cooler 2, a load 4, and an expansion machine 5, and it also comprises conduit means which connect those elements of structure into a closed cycle for flow of the gaseous working fluid from the compressor to the cooler, thence to the load, thence to the expansion machine, and thence back to the compressor. These conduit means moreover provide for delivery of heat by heat exchange, as in the exchanger 3 of FIG. 1, from compressed gas flowing between the cooler and load to expanded gas flowing between the expansion machine and compressor. In the embodiment of FIG. 2 these conduit means additionally provide for flow of heat exchange, as in the exchanger 6 of FIG. 2, from gas flowing between the cooler and load (and downstream of the exchanger 3) to gas flowing between the load 4 and expansion machine 5, and also for flow of heat by heat exchange, as in the exchanger 7 of FIG. 2, from gas flowing between the cooler and load (and downstream of the exchanger 6 of FIG. 2)

6

to gas flowing from the expansion machine 5 toward the compressor 1.

Although the gaseous working medium is warmed in the load, the interposition of the exchanger 7 between the exchanger 6 and the load makes it possible for each of those exchangers to lower the temperature of the cooling medium flowing therethrough toward the load, and the provision of those exchangers (more especially of the exchanger 6) raises the average temperature of the cooling medium in the turbine 5.

This beneficial raising of the average temperature of the cooling medium in the expansion machine is achieved in the embodiment of FIG. 3 by provision of the exchanger 9, and the ability of the exchanger 9 to abstract heat from the coil 17 thereof into coil 18 thereof, notwithstanding the rise in temperature undergone by the cooling medium in the load exchanger 4 of that figure, is insured by the provision of coil 11 in exchanger 10, downstream of coil 17 in exchanger 9, with coil 11 in heat exchange relation with coil 16, coil 11 delivering heat to coil 16.

In respect of the operation of exchangers 9 and 10 with their coils 17, 18 and 8, 11, 16, the embodiments of FIGS. 4 and 5 are similar to that of FIG. 3.

While the invention has been described herein in terms of a number of presently preferred exemplary embodiments, the invention itself is not limited thereto but rather comprehends all modifications on and departures from the systems hereinabove specifically described which fall within the spirit and scope of the appended claims.

I claim:

1. A gas cooling system comprising a compressor, a load, an expansion machine, first and second heat exchangers, each of said exchangers including two channels in heat exchange relation, and conduit means connecting the compressor, machine, heat exchangers and load into a closed cycle for flow of gas from the compressor to one channel of the first heat exchanger, to one channel of the second heat exchanger, to the load, to the other channel of the first heat exchanger, to the machine, to the other channel of the second heat exchanger, and back to the compressor.

2. A gas cooling system according to claim 1 including plural series-connected expansion machines.

References Cited

UNITED STATES PATENTS

3,194,026 7/1965 La Fleur ----- 62—88

WILLIAM J. WYE, *Primary Examiner*.