Aug. 7, 1962 D. K. COLES ET AL 3,048,021

JOULE-THOMSON EFFECT GAS LIQUEFIER

Filed Feb. 17, 1959

Fig.1.

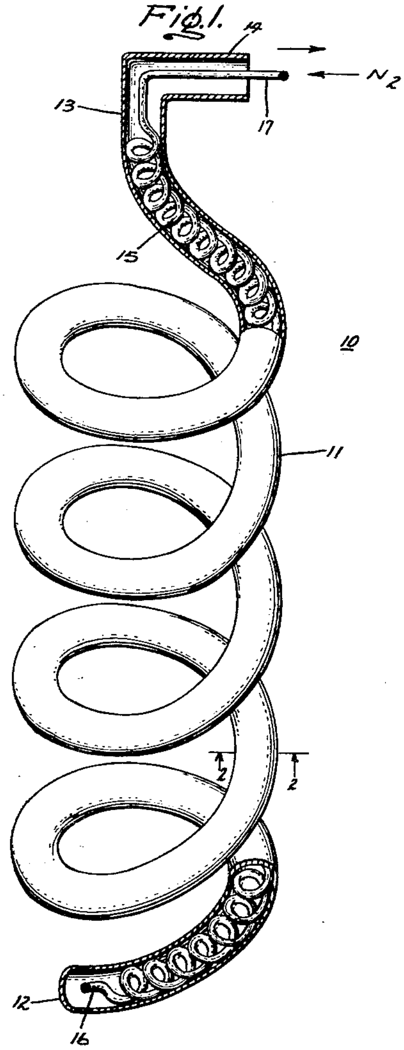


Fig.2.

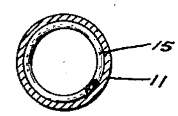


Fig.3.

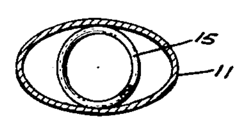


Fig.4.

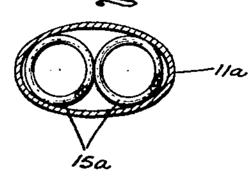


Fig.6.

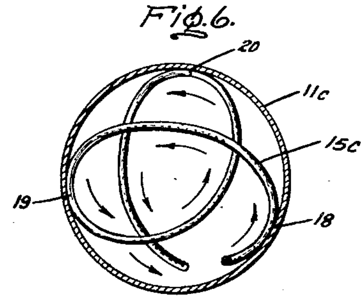
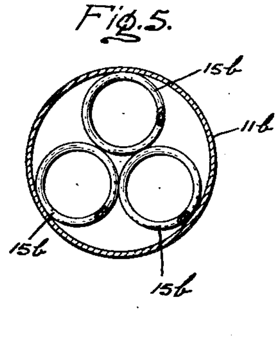


Fig.5.



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United States Patent Office

3,048,021
Patented Aug. 7, 1962

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3,048,021

JOULE-THOMSON EFFECT GAS LIQUEFIER

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Filed Feb. 17, 1959, Ser. No. 793,863
11 Claims. (Cl. 62—36)

This invention relates generally to cooling devices for providing extremely low temperatures and more particularly to cooling devices of the Joule-Thomson gas liquefier type.

Joule-Thomson effect cooling devices are well known in the art and are employed where it is desired to obtain extremely low temperatures; Joule-Thomson effect cooling devices are capable of producing temperatures as low as −196° C. Such devices conventionally include an elongated, straight thin-wall tube or jacket having a closed lower end and a low pressure gas discharge opening adjacent its other end. Entering the jacket adjacent the low pressure gas discharge end is a small diameter elongated capillary tube extending downwardly in a "coiled coil" configuration, and terminating in a small nozzle adjacent the closed end of the jacket. Gas having a Joule-Thomson coefficient which is positive at room temperature, such as nitrogen, is supplied under high pressure to the capillary tube and expands through the nozzle. This expansion of gas from the nozzle causes initial cooling and the gas then flows upwardly over the convolutions of the capillary tubing, thus extracting further heat from the tubing and the gas flowing downwardly therein, the gas at reduced pressure being finally exhausted to the atmosphere through the low pressure discharge opening of the jacket. Such Joule-Thomson gas liquefiers (commonly referred to as cryostats) have commonly been employed for cooling infrared cells, typically being inserted in a cooling well formed as a reentrant tubular portion in the enclosing envelope of the cell.

Prior conventional cryostat devices of the type employing "coiled coil" capillary tubes known to the present applicants have been required to be of substantial length in order to provide sufficient cooling, this length in turn dictating the over-all length of the infrared cell. Furthermore, prior conventional cryostat constructions have had a serious heat leak along the outer jacket by virtue of its over-all length and substantial diameter. Furthermore, the long length of capillary tubing presently employed in conventional cryostats has necessitated a substantial nitrogen flow from a source providing nitrogen at relatively high pressure, e.g., five (5) litres per minute from a two thousand (2000) pounds per square inch source. There are requirements, however, for infrared cells having substantially shorter length than prior cells which in turn necessitates the provision of substantially shorter cryostat devices. However, to the best of the present applicants' knowledge, all efforts to shorten conventional cryostat designs by increasing their diameter have resulted in failure, even though the same effective length of capillary tubing was utilized. In addition, it is desirable to provide a cryostat device requiring a considerably smaller nitrogen flow than prior cryostat constructions, i.e., two (2) to three (3) litres per minute versus four (4) to five (5) litres per minute, and an additional requirement that the nitrogen reservoir supply nitrogen at a lower pressure than has heretofore been possible.

It is therefore desirable to provide a Joule-Thomson gas liquefier which will provide the same cooling effect as prior devices of this type, but having a substantially shorter length than has heretofore been possible. It is further desirable that such a Joule-Thomson effect cooling device be capable of fabrication in considerably larger diameters than has been found to be possible with prior conventional cryostat constructions. Furthermore, it is desirable to provide a cryostat construction providing the same cooling as provided by prior constructions employing, however, a substantially smaller nitrogen flow from a lower pressure source of gas.

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It is therefore an object of our invention to provide an improved Joule-Thomson gas liquefier.

Another object of our invention is to provide an improved Joule-Thomson gas liquefier providing the same cooling effect in a substantially shorter length than prior devices of this type.

A further object of this invention is to provide an improved Joule-Thomson gas liquefier providing the same cooling effect as prior devices of this type with a smaller gas flow and lower gas supply pressure than has heretofore been possible.

Yet another object of our invention is to provide an improved Joule-Thomson gas liquefier possessing the desirable features enumerated above.

Our invention in its broader aspects provides a Joule-Thomson gas liquefier having a first elongated convolute tube having a closed end and a low pressure gas discharge opening adjacent its other end and a second elongated convolute tube positioned in the first tube and having a gas discharge opening at one end adjacent the closed end of the first tube and having its other end extending out of the first tube adjacent the other end thereof and adapted to be connected to a supply of high pressure gas. In accordance with a preferred embodiment of our invention, the inner elongated tube is coiled in a helix substantially throughout its length, and is positioned in the first tube in good thermal contact with the inner wall thereof, the outer tube with the helically coiled inner tube therein being coiled in a helix substantially throughout its length.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a view in perspective, partly broken away, illustrating the improved Joule-Thomson gas liquefier construction of our invention;

FIG. 2 is a cross-sectional view taken along the line 2—2 of FIG. 1;

FIG. 3 is a cross-sectional view similar to FIG. 2 illustrating a slightly modified form of our invention;

FIGS. 4 and 5 are cross-sectional views illustrating another embodiment of our invention; and

FIG. 6 is a cross-sectional view illustrating a further embodiment of our invention.

Referring now to FIGS. 1 and 2 of the drawings, we have here provided a Joule-Thomson gas liquefier, generally identified as **10** which includes an efficient and compact heat exchanger with low thermal conductance between the two ends thereof. In accordance with our invention, the Joule-Thomson gas liquefier **10** comprises an elongated outer tube or jacket **11** having its end **12** closed, as by a heliarc weld, and with its other end **13** having a low pressure gas exhaust passageway **14** communicating with the atmsophere, as shown. Positioned within the elongated outer tube **11** is an inner elongated capillary tube **15** having a gas discharge nozzle **16** at its lower end adjacent the closed end **12** of the outer tube **11**, and having its other end **17** extending out of the exhaust passageway **14** of the outer tube **11**, adapted to be connected to a supply of high pressure gas (not shown) such as nitrogen. As shown in the broken away portions of FIG. 1, and also in the cross-sectional view of FIG. 2, the elongated inner tube **15** is coiled into a simple helix substantially throughout its length and in the embodiment of FIGS. 1 and 2, fits snugly within the outer tube **11** and in good thermal contact with the inner wall thereof. In addition, the outer tube **11** with the helically coiled inner tube **15** therein is coiled in a simple helix substantially throughout its length, this helix having a diameter several times larger than the diameter of the outer tube **11**, as shown.

When employed as a Joule-Thomson gas liquefier, high pressure gas, such as nitrogen, at one hundred atmospheres pressure, is introduced to the high pressure end **17** of the inner tube **15**. This gas then flows downwardly in the convolutions of the inner tube **15** toward the nozzle end **16**, the nozzle being preferably somewhat constricted so that a suitable pressure drop takes place near the nozzle end **16** of the inner tube **15**. After being exhausted from the nozzle **16** of the inner tube **15**, the pressure of the gas is much lower than previously so that the gas then expands. Associated with this expansion is a cooling effect, known as the Joule-Thomson effect. By virtue of the provision of the closed end **12** of the outer tube **11**, the expanded gas exhausted from the nozzle **16** of the inner tube **15** is forced to retrace its path upwardly over the convolutions of the inner tube **15**, extracting heat from the newly entering gas in the inner tube **15** and being in turn warmed; this mode of operation is commonly referred to as counter-current heat exchange. Once operation of the device has started, the newly entering gas is precooled and on being exhausted from the nozzle **16** of the inner tube **15**, cools itself on expansion to a still lower temperature, finally resulting in the provision of an extremely low temperature.

It will now be seen that in contrast with prior conventional Joule-Thomson gas liquefier constructions in which the expanded gas followed a straight line path upwardly over the convolutions of the coiled-coil capillary tube, in our improved construction, the expanded gas follows a much longer spiral path, thus increasing the heat exchanging effect without increasing the over-all length of the device, or on the other hand providing the same heat exchanging effect with a much shorter over-all length. In addition, it will be observed that the heat leakage along the outer jacket of the prior devices has been reduced through the reduction of the diameter of the outer tube or jacket **11** and also by the increase in its spiral length.

In a cryostat device constructed in accordance with our invention, the outer and inner tubes **11** and **15** respectively are preferably formed of metal having a comparatively low thermal conductivity, such as stainless steel. In the assembly of the device of FIGS. 1 and 2, the inner tube **15** is first coiled up in its helically coiled form and is then inserted in the outer tube **11** which is then in turn coiled up to provide the helical configuration shown in FIG. 1. In order to increase the thermal conductance between the outer tube **11** and the inner tube **15**, we have found it desirable to copper-plate the inner tube **15** lightly prior to its insertion in the outer tube **11**. The outer tube **11** with the coiled and plated inner tube **15** is then wound into the helical form shown, and the resulting assembly is then heated in a hydrogen furnace until the copper-plating on the inner tube **15** forms a braze between the inner and outer tubes **15** and **11**.

Referring now briefly to FIG. 3, it will be readily understood that the outer tube **11** may be deformed during the operation of winding it into helical form so that it is generally elliptical in cross section, as shown, thus grasping the convolutions of the inner tube **15** more tightly thereby to increase the efficiency of heat exchange.

Referring now to FIGS. 4 and 5, it will be observed that it may be desirable to provide several inner helically coiled tubes effectively connected in parallel. Thus, in FIG. 4, we have shown two inner tubes **15*a*** positioned with outer tube **11*a***; the inner tubes **15*a*** respectively being disposed in side-by-side relationship, and being in thermal contact with the inner wall of the outer tube **11*a*** as shown. In FIG. 5, we have shown the provision of three inner tubes **15*b***, likewise positioned within the outer tube **11*b*** in abutting side-by-side relationship, and again in thermal contact with the outer tube **11*b***.

Referring now to FIG. 6, it will be observed that the inner tube **15*c*** may have a complex helical configuration, as shown, with each successive convolution, such as **18**, **19** and **20** being in thermal contact with the inner wall of the outer tube **11*c*** at angularly spaced points, as shown.

In an actual cryostat device constructed in accordance with our invention, the heat exchanger length was ¾ inch, compared with a length of 2½ inches in a comparable cryostat of conventional construction. The diameter of the helix of the outer tube **11** of the device in accordance with our invention was ⅜ inch with the outer tube **11** having a diameter of .090 inch, compared with an outside diameter of .188 inch in the case of the prior conventional device; it is thus observed that in accordance with our invention, it is possible to construct a Joule-Thomson gas liquefier device having a considerably larger over-all outside diameter than has previously been possible with conventional constructions. In the device in accordance with our invention, the outer tube **11** had an inside diameter of .070 inch and the inner tube **15** had an outside diameter of .020 inch and an inside diameter of .010 inch. With this device, a temperature of −194° was obtained, with a nitrogen flow of two (2) litres per minute from a source of nitrogen of 1200 pounds per square inch compared with a nitrogen flow of five (5) litres per minute from a source of nitrogen having a pressure of 1700 pounds per square inch in the case of a comparable conventional cryostat construction. It is thus seen that a much smaller volume of nitrogen from a source having a considerably lower pressure is employed with our improved cryostat construction.

While we have described above the principles of our invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of our invention.

What is claimed is:

1. A Joule-Thomson gas liquefier comprising: a first elongated convolute tube having a closed end and a low pressure gas discharge opening adjacent its other end; and a second elongated convolute tube positioned in said first tube in contact therewith and having a gas discharge opening at one end thereof adjacent said closed end of said first tube, the direction of curvature of said second convolute tube being angularly disposed to the direction of curvature of said first convolute tube, said second tube having its other end extending out of said first tube adjacent said other end thereof and adapted to be connected to a supply of high pressure gas.

2. A Joule-Thomson gas liquefier comprising: a first elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and a second elongated tube having a gas discharge opening at one end thereof, said second tube being coiled in a helix substantially throughout its length and being positioned in said first tube in contact therewith, said second tube having said gas discharge opening end positioned adjacent said closed end of said first tube and having its other end extending out of said first tube adjacent said other end thereof and adapted to be connected to a supply of high pressure gas; said first tube with said second tube therein being coiled in a helix substantially throughout its length, the direction of curvature of said second tube being angularly disposed to the direction of curvature of said first tube.

3. A Joule-Thomson gas liquefier comprising: a first elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and a sec-

ond elongated tube having an outside diameter substantially smaller than the inside diameter of said first tube and having a gas discharge opening at one end thereof, said second tube being coiled in a helix substantially throughout its length and being positioned in said first tube in thermal contact with the inner wall thereof, said second tube having said gas discharge opening end positioned adjacent said closed end of said first tube and having its other end extending out of said first tube adjacent said other end thereof and adapted to be connected to a supply of high pressure gas; said first tube with said second tube therein being coiled in a helix substantially throughout its length with a diameter several times greater than the outside diameter of said first tube, the direction of curvature of said second tube being angularly disposed to the direction of curvature of said first tube.

4. A Joule-Thomson gas liquefier comprising: a first elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and a second elongated tube having an outside diameter substantially smaller than the inside diameter of said first tube and having a gas discharge opening at one end thereof, said second tube being coiled in a helix substantially throughout its length with a diameter substantially equal to the inside diameter of said first tube, said second tube being positioned in said first tube in thermal contact with the inner wall thereof with its gas discharge opening end adjacent said closed end of said first tube and its other end extending out of said first tube adjacent said other end thereof and adapted to be connected to a supply of high pressure gas; said first tube with said second tube therein being coiled in a helix substantially throughout its length with a diameter several times greater than the outside diameter of said first tube, the direction of curvature of said second tube being angularly disposed to the direction of curvature of said first tube.

5. A Joule-Thomson gas liquefier comprising: a first elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and a second elongated tube having an outside diameter substantially smaller than the inside diameter of said first tube and having a gas discharge opening at one end thereof, said second tube being coiled in a helix substantially throughout its length and being positioned in said first tube in thermal contact with the inner wall thereof, said second tube having said gas discharge opening end positioned adjacent said closed end of said first tube and having its other end extending out of said first tube adjacent said other end thereof and adapted to be connected to a supply of high pressure gas; said first tube with said second tube therein being coiled in a helix substantially throughout its length with a diameter several times greater than the outside diameter of said first tube, the direction of curvature of said second tube being angularly disposed to the direction of curvature of said first tube; said second tube being brazed to said inner wall of said first tube.

6. A Joule-Thomson gas liquefier comprising: a first elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and a second elongated tube having an outside diameter substantially smaller than the inside diameter of said first tube and having a gas discharge opening at one end thereof, said second tube being coiled in a helix substantially throughout its length and being positioned in said first tube in thermal contact with the inner wall thereof, said second tube having said gas discharge opening end positioned adjacent said closed end of said first tube and having its other end extending out of said first tube adjacent said other end thereof and adapted to be connected to a supply of high pressure gas; said first tube with said second tube therein in being coiled in a helix substantially throughout its length with a diameter several times greater than the outside diameter of said first tube, the direction of curvature of said second tube being angularly disposed to the direction of curvature of said first tube; said first and second tubes being respectively formed of relatively low thermal conductivity metal, said second tube being plated with a relatively low melting point metal and brazed to said inner wall of said first tube.

7. A Joule-Thomson gas liquefier comprising: a first elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and a second elongated tube having an outside diameter substantially smaller than the inside diameter of said first tube and having a gas discharge opening at one end thereof, said second tube being coiled in a helix substantially throughout its length and being positioned in said first tube in thermal contact with the inner wall thereof, said second tube having said gas discharge opening end positioned adjacent said closed end of said first tube and having its other end extending out of said first tube adjacent said other end thereof and adapted to be connected to a supply of high pressure gas; said first tube with said second tube therein being coiled in a helix substantially throughout its length with a diameter several times greater than the outside diameter of said first tube, the direction of curvature of said second tube being angularly disposed to the direction of curvature of said first tube; said first tube having a generally elliptical cross-section in its coiled portion and intimately engaging the coils of said second tube.

8. A Joule-Thomson gas liquefier comprising: an outer elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and at least two inner elongated tubes, each of said inner tubes having a gas discharge opening at one end thereof and being coiled in a helix substantially through its length, said inner tubes being positioned in said outer tube with their gas discharge opening ends respectively positioned adjacent said closed end of said outer tube and with their other ends respectively extending out of said outer tube and adapted to be supplied with high pressure gas; said outer tube with said inner tubes therein being coiled in a helix substantially throughout its length the direction of curvature of each of said inner tubes being angularly disposed to the direction of curvature of said outer tube.

9. A Joule-Thomson gas liquefier comprising: an outer elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and at least two inner elongated tubes, each of said inner tubes having a gas discharge opening at one end thereof and being coiled in a helix substantially throughout its length, said inner tubes being positioned in said outer tube in side-by-side abutting relationship and respectively in thermal contact with the inner wall of said outer tube, said inner tubes having their gas discharge ends respectively positioned adjacent said closed end of said outer tube and having their other ends respectively extending out of said outer tube and adapted to be supplied with high pressure gas; said outer tube with said inner tubes thereon being coiled in a helix substantially throughout its length the direction of curvature of each of said inner tubes being angularly disposed to the direction of curvature of said outer tube.

10. A Joule-Thomson gas liquefier comprising: a first elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and a second elongated tube having an outside diameter substantially smaller than the inside diameter of said first tube and having a gas discharge opening at one end thereof, said second tube being coiled in simple helix substantially throughout its length and being positioned in said first tube in thermal contact with the inner wall thereof, said second tube having said gas discharge opening end positioned adjacent said closed end of said first tube and having its other end extending out of said first tube adjacent said other end thereof and adapted to be connected to a supply of high pressure gas; said first tube with

said second tube therein being coiled in a simple helix substantially throughout its length, the direction of curvature of said second tube being angularly disposed to the direction of curvature of said first tube.

11. A Joule-Thomson gas liquefier comprising: a first elongated tube having a closed end and a low pressure gas discharge opening adjacent its other end; and a second elongated tube having an outside diameter substantially smaller than the inside diameter of said first tube and having a gas discharge opening at one end thereof, said second tube being coiled in a complex helix substantially throughout its length, said second tube being positioned in said first tube with each convolution of said second tube having a portion in thermal contact with the inner wall of said first tube, said second tube having said gas discharge opening end positioned adjacent said closed end of said first tube and having its other end extending out of said first tube adjacent said other end thereof and adapted to be connected to a supply of high pressure gas; said first tube with said second tube therein

being coiled in a simple helix substantially throughout its length, the direction of curvature of said second tube being angularly disposed to the direction of curvature of said first tube.

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