Sept. 2, 1969 J. A. RIETDIJK 3,464,230

SYSTEMS FOR PRODUCING COLD AND EJECTORS IN SUCH SYSTEMS

Filed June 28, 1967 3 Sheets-Sheet 1

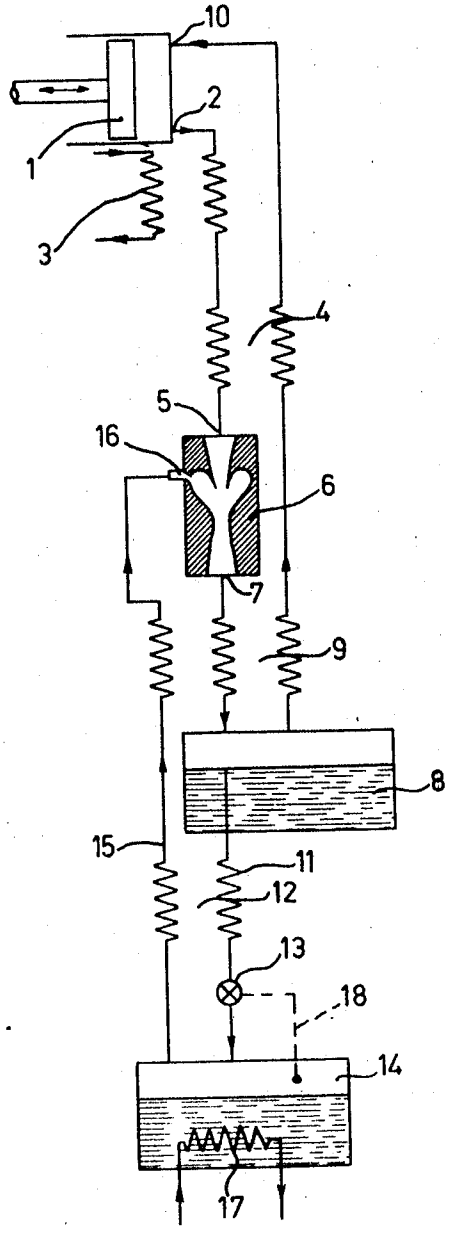

FIG.1

INVENTOR.
JOHAN A.RIETDIJK

BY

Frank R. Trifari
AGENT

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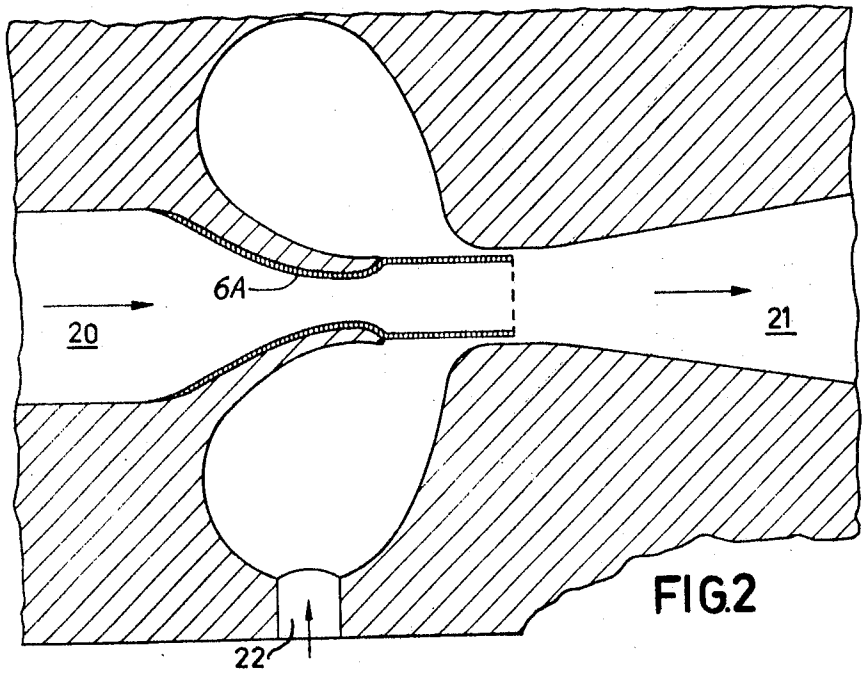

FIG.2

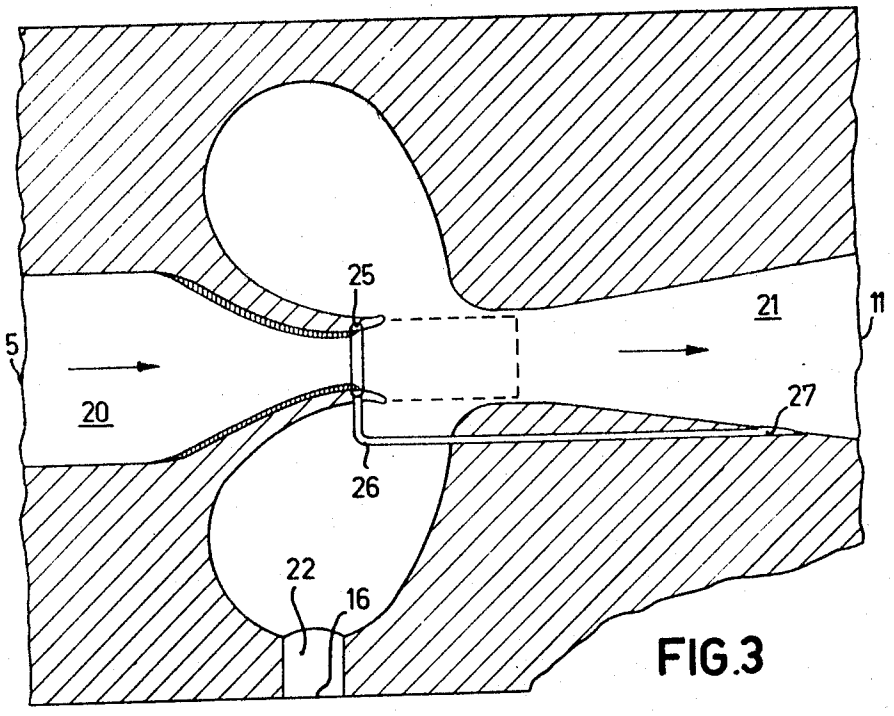

FIG.3

INVENTOR.
JOHAN A.RIETDIJK
BY
Frank R. Trifari
AGENT

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SYSTEMS FOR PRODUCING COLD AND EJECTORS IN SUCH SYSTEMS

Filed June 28, 1967 3 Sheets-Sheet 3

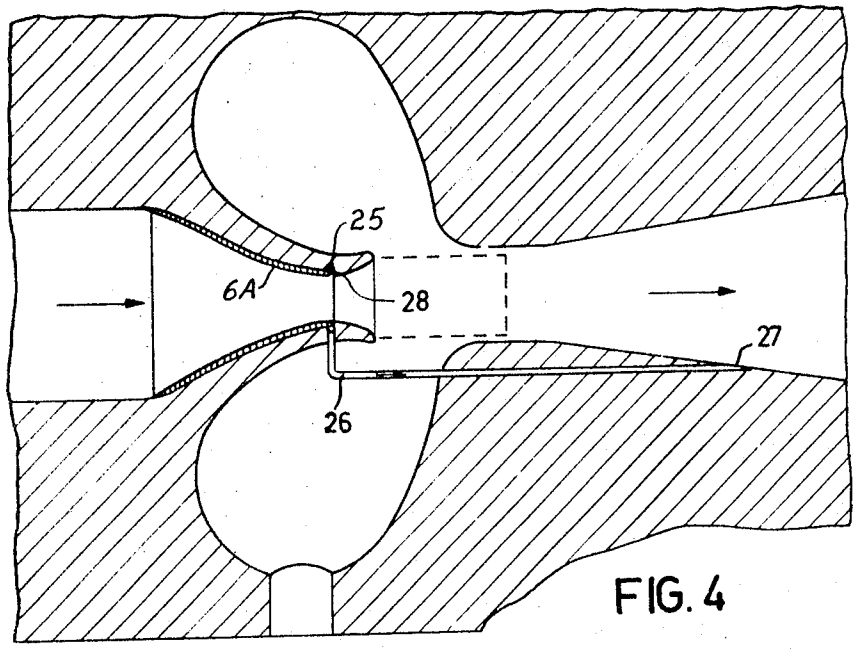

FIG. 4

INVENTOR.
JOHAN A RIETDIJK

BY

AGENT

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SYSTEMS FOR PRODUCING COLD AND EJECTORS IN SUCH SYSTEMS

Johan Adriaan Rietdijk, Emmasingel, Eindhoven, Netherlands, assignor, by mesne assignments, to U.S. Philips Corporation, New York, N.Y., a corporation of Delaware

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Claims priority, application Netherlands, July 1, 1966 6609174
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U.S. Cl. 62—500 8 Claims

ABSTRACT OF THE DISCLOSURE

This invention relates to apparatus for producing cold wherein fluid medium from a high pressure source is: first cooled to its inversion temperature associated with that pressure, and then expanded in an ejector and discharged to first reservoir with vapor therefrom returning to said source; subsequently medium from the reservoir is further expanded in a throttling device, and discharged to a second reservoir with vapor therefrom being pumped in the suction inlet of the ejector. The ejector has jet pipe and diffuser portions through which the medium flows, and means for separating a boundary layer of the medium from the inner walls of the jet pipe portion where this layer tends to form, the separation means being a duct communicating to a zone of relatively lower pressure.

The invention for producing cold and/or for liquefying gases comprises at least one inlet for high-pressure medium, communicating with one or more heat exchangers in which the high-pressure medium is cooled to the inversion temperature associated with the the pressure concerned. The system further comprises at least one member in which the cooled high-pressure medium is reduced in pressure, and one or more reservoirs in which the lower-pressure medium is in thermal contact with a place to be cooled or can be withdrawn from the system in the liquid state. There is also provided a duct system for conducting away the lower-pressure medium, if desired, through one or more of said heat exchangers.

In known systems of the kind set forth the desired reduction of pressure is achieved by using Joule-Kelvin cocks, in which the high-pressure medium is throttled to a considerably lower pressure. With an appropriate choice of pressure and temperature the throttle process will result in a drop of temperature of the medium or a change of phase of part of the medium or in both. The lower-pressure medium can then be brought into thermal contact with an object to be cooled or a medium to be cooled. If the state of the medium has changed, part of the resultant liquid may, if desired, be withdrawn from the system. The developed low-pressure vapor is then conducted away to the surroundings or supplied back to a compressor, which supplies the high-pressure medium.

In order to attain very low temperatures it is necessary to throttle to very low pressures. If helium is used as a medium and if it is desired to attain a temperature of 4.2° K., throttling is required to about 1 ata.; 3.6° K. requires throttling to about 0.5 ata. Still lower temperatures requires choking to still lower pressures. This means that in a closed system the compressor has to be very large, while the low-pressure sides of the heat exchangers must have a low flow resistance. The known systems are therefore complicated and expensive. If an open system is employed in which high-pressure medium is obtained from some source whereas the lower-pressure medium

is conducted away to the surroundings subsequent to heat exchange with an object to be cooled, and if cold has to be provided at temperatures associated with a subatmospheric pressure, the system cannot blow off automatically. Therefore additional measures are required for conducting the lower-pressure medium out of the system. The known systems have a further disadvantage in that the pressure energy of the high-pressure medium is dissipated directly in the Joule-Kelvin cocks which involves losses.

In order to obviate all these disadvantages there is proposed a system which is characterized, in its operation, with at least one of said reservoirs having a pressure which is lower than the pressure at which the medium is conducted away from the ejector; also the member in which the pressure is reduced, comprises at least one ejector to which at least part of the cooled, high-pressure medium can be supplied, the suction side of said ejector being in communication with said reservoir in which the lower pressure prevails, whereas the outlet communicates with the duct system through which the lower pressure medium can be conducted out of the system. In the scope of the present invention the term ejector is to be understood to mean a member in which the potential energy of a high-pressure (primary) medium is converted wholly or partly into kinetic energy, which is utilized at least partly for raising the pressure of a second (secondary) medium.

In the proposed system the energy of the high-pressure medium supplied to the ejector is utilized at least partly for withdrawing the vapour from the lower-pressure reservoir and for adjusting the pressure of this vapour to that of the duct system; also some lower-pressure medium is conducted out of the system. The cold can thus be obtained at a pressure lower than the pressure at the outlet. This involves the advantage that the compressor, the suction side of which communicates with said outlet, can then operate with a considerably lower pressure ratio than is the case in known systems.

The difference between the prior art systems and the system proposed consists in that the pressure energy of the medium supplied to the ejector is not directly dissipated, but is utilized to pump up the vapour from the lower-pressure reservoir to the suction pressure of the compressor or to the pressure at which the medium leaves the system. The system thus obtained has an improved efficiency and a considerably more favourable pressure ratio in the heat exchangers and the compressor.

In the system proposed the vapour developed in the lower-pressure reservoir is conducted away by means of an ejector. The pressure this reservoir above the liquid contained therein determines the temperature of the cold obtained. The present situation is such that there is a growing demand for systems providing cold of temperatures approaching the absolute zero point. These lower temperatures are associated with lower pressures above the liquid contained in the further reservoir. If the system contains helium, and if cold of about 1° K. has to be provided, the vapour pressure above the liquid has to be 0.12 mm. Hg. In order to obtain cold of this temperature, the ejector must be capable of withdrawing vapour of 0.12 mm. Hg, which means that the ejectors can perform their suction action normally only up to a given pressure.

The invention has for its object to provide a system of the kind set forth, which comprises an ejector capable of withdrawing medium at lower pressures than the known ejectors. The system according to the invention is characterized in operation whereby at least one of said reservoirs has a pressure which is lower than the pressure at which the medium is conducted out of the system, and the member in which the pressure is reduced comprises at least one ejector. At least part of the cooled,

high-pressure medium can be supplied to the jet pipe of each ejector, and the suction side of at least one of these ejectors communicates with at least one of said lower-pressure reservoirs, while the outlet of one reservoir communicates with the duct system through which the lower-pressure medium can be conducted out of the system. At least one of the ejectors is provided with means for separating the boundary layer of fluid medium formed on the wall of the jet pipe from the high-pressure medium flow.

The boundary layer formed on the wall of the jet pipe has a lower speed than the main flow of the high-pressure medium and surrounds the main medium flow of higher speed like a lower sheath speed after the flow has emerged from the jet pipe. Owing to the lower speed this sheath is considerably less effective with respect to the suction power than the main flow of higher speed. Since the sheath of lower speed medium screens the main flow, the suction power of the ejector is chiefly determined by said sheath, and since the peripheral sheath of lower speed constitutes a zero load for the ejector, it will be obvious that this peripheral sheath adversely affects the efficiency and the lowest attainable suction pressure of the ejector. In accordance with the invention, by separating this peripheral sheath from the main flow and by removing it, the portion of the flow of higher suction power is better utilized, so that the ejector is capable of performing a suction operation down to lower pressures, and the system is capable of providing cold of lower temperatures than the known systems.

In a further, advantageous system embodying the invention the sepaarting means are formed by an annular recess in the wall of the jet pipe for the high-pressure medium, which recess is preferably provided as near the end of the jet pipe as possible and communicates through one or more ducts with a place of lower pressure than that at the annular recess. The place of lower pressure may be formed by a pump which sucks away the peripheral layer or by a further ejector removing the boundary layer. As a further alternative, the place of lower pressure may be formed by an area of the medium flow farther away in the downstream direction.

In another embodiment of the invention the diameter of the jet pipe at the area of the recess tapers in the direction of flow, thus forming a step in the wall of the jet pipe, whereby the boundary layer is satisfactorily separated off the wall. A further embodiment has separating means formed by a sharply defining diaphragm which is disposed after the jet pipe and has a diameter smaller than the diameter of the end of the jet pipe, while one or more ducts communicate between the diaphragm and the jet pipe, and at a place of lower pressure.

The invention also relates to an ejector suitable for use in systems of the kind set forth, wherein the ejector comprises a jet for the high-pressure medium supplied thereto, a diffuser for conducting away lower-pressure medium, and an inlet for a medium to be drawn in, opening out between the jet pipe and the diffuser. This ejector is characterized in that it is provided with means for separating the boundary layer formed on the wall of the outlet tube from the high-pressure medium flow. Structurally this ejector may be formed as described in the foregoing.

It will be obvious that apart from the structural embodiments described above, numerous other embodiments may be suggested without departing from the essential idea of the invention, which will be described more fully with reference to the drawings.

FIG. 1 shows diagrammatically, not to scale, one embodiment of a system including an ejector for providing cold at lower temperature.

FIG. 2 shows on an enlarged scale a cross section of an ejector.

FIGS. 3 and 4 show, on an enlarged scale, diagrammatically three embodiments of ejectors provided with means for separating the boundary layer of the high-

pressure medium formed on the wall of the outlet tube from the main flow of the high-pressure medium.

FIG. 1 shows a system comprising a compressor **1** having an outlet **2** which communicates through a cooler **3** with the high-pressure part of the heat exchanger **4** and then communicates with the inlet side **5** of an ejector **6**. The ejector's outlet **7** is connected through a heat exchanger **9** with a collecting reservoir **8** with vapour space of the reservoir **8** communicating through heat exchangers **9** and **4** and with the suction side **10** of the compressor **1**. The collecting reservoir **8** also communicates through a duct **11**, a heat exchanger **12**, and a choking cock **13**, with a further reservoir **14**. The vapour space of the reservoir **14** communicates through a duct **15** including heat exchangers **12** and **9** with the suction side **16** of the ejector **6**. The reservoir **14** accommodates a helical duct **17**, through which a medium to be cooled can be passed. Instead of this cooling helix the reservoir may comprise another object to be cooled, for example, a memory store or a calculating element of an electronic computer. The system comprises furthermore a control-member **18** for the choking member **13**, operating in dependence upon the liquid level in the reservoir **8** and/or **14**.

This system operates as follows. The compressor **1** compresses a medium such as helium, to a pressure P_1. This high-pressure medium is cooled in the cooler **3** and the heat exchanger **4** to below its inversion temperature and then supplied to the ejector **6**. In this ejector the pressure of the medium is reduced, while the potential energy is partly converted into kinetic energy, which is partly utilized for adjusting the pressure of the low-pressure vapour of the reservoir **14**. The medium leaving the ejector with a pressure P_2 is collected in a reservoir **8**, and the vapour therein also at pressure P_2 can flow back through the heat exchangers **9** and **4** to the suction side **10** of the compressor **1**. The resultant liquid in this reservoir is choked in the choking cock **13** to a pressure P_3, which is associated with the temperature of the cold to be provided.

The vapour at the pressure P_3 in the reservoir **14** is conducted away via duct **15** to the ejector's suction inlet **16**, and adjusted to the pressure P_2 of the collecting reservoir **8**. Before entering the ejector **6**, the vapour of the reservoir **14** exchanges heat with the higher-pressure medium in the heat exchangers **12** and **9**. In the ejector **6** the energy of the high-pressure medium is partly utilized for withdrawing vapour from the reservoir **14**, and for pumping up the withdrawn vapour to a pressure P_2 since the pressure P_3, prevailing in the reservoir **14** and corresponding to the desired lower temperature, may in this case be considerably lower than the pressure P_2 of the reservoir **8**. Consequently, in this system the compressor operates between the pressures P_2 and P_1, so that its construction may be much simpler than in the known system in which the compressor operates between the pressures P_3 and P_1.

Instead of using the system for producing cold, which is shown by way of example in FIG. 1 and in which the expansion of the high-pressure medium takes place mainly in the ejector **6**, other embodiments of such a system may be employed, which are described in Dutch patent application 6,414,856 which corresponds to U.S. application No. 511,044, filed Dec. 2, 1965.

The ejector **6**, which may in practice have the dimensions of a match box, is shown diagrammatically and enlarged in FIG. 2. This ejector comprises a jet pipe **20** for the high-pressure medium, a diffuser **21** for conducting away expanded medium, and an inlet **22** for the medium to be received. When the high-pressure medium passes through the jet pipe, a boundary layer will be formed on the wall of the pipe, and the speed of this layer drops to zero. The variation of speed on the outlet side of the jet pipe is indicated by a broken line, and it appears that the core of the emerging medium flow has a speed V, which is preferably higher than the speed of sound, while this core is surrounded by an annular sheath of a medium,

whose speed drops from the value V to zero value. Although the boundary layer, indicated by vertical cross-hatching *6a*, and the sheath of lower-speed medium surrounding the main flow of the medium have only a very small thickness of about 3μ, this boundary layer forms a load for the suction power of the ejector. Owing to its lower speed this sheath has a lower suction power than the core of the flow. The suction power of the ejector is furthermore determined mainly by the medium of the sheath, since the latter screens the core and therefore this sheath will be a factor to determine the attainable minimum suction pressure of the ejector.

FIG. 3 shows another ejector, the main parts of which correspond with the ejector of FIG. 2. However, the wall of the jet pipe of this ejector is provided with a recess **25**, which communicates through a duct **26** with a remote place located in the diffuser where a lower pressure prevails than at the place of the recess **25**. Therefore the boundary layer formed on the wall of the jet pipe **20** will be conducted away through the duct **26**. By providing the recess **25** near the end of the jet pipe **20**, the flow of medium will emerge from the pipe **20** substantially without a boundary layer, so that its variation in speed assumes the form indicated by the broken line and which is approximately constant and therefore highly conducive to the suction power of the ejector, since the portion of the flow of the high speed is no longer screened by a sheath of lower speed, the reservoir **14** can be emptied to a lower pressure, with the result that cold can be provided of a lower temperature than hitherto possible.

Although the duct **26** of the embodiment shown in FIG. 3 opens out in the diffuser at the point **27**, for conducting away the peripheral layer, this layer may be removed in other manners, such as by connecting the duct **26** through the heat exchangers **9** and **4** with the suction side of the compressor, or connecting this duct **26** by its side remote from the recess **25** with a separate suction pump or a separate suction ejector.

FIG. 4 shows the ejector of FIG. 2, in which the peripheral layer *6a* is conducted away by means of the duct **26**, which opens out in the recess **25** at a place of the wall of the jet pipe where it abruptly assumes a smaller diameter, so that a step **28** is formed. The removal of the peripheral layer is thus improved as compared with the embodiment of FIG. 3. Since it is important that the emerging flow of medium should be completely free of the peripheral layer, the recess **25** and the step **28** have to be positioned as near the end of the jet pipe as possible.

From the foregoing it will be apparent that the invention is based on the recognition of the fact that the suction power and the attainable minimum suction pressure of an ejector are harmfully affected by the peripheral layer formed on the wall of the jet pipe and that this drawback can be obviated by separating this peripheral layer from the main flow of the high-pressure medium. As a matter of fact, a great number of constructions may be designed for separating this peripheral layer, three of which are described herein by way of example. By this separation of the peripheral layer the effect of the ejector, particularly the suction power, is considerably improved, so that the vapour pressure above the liquid in the reservoir providing the cold may be considerably lower than in the systems known, so that the cold provided may have considerably lower temperatures.

What is claimed is:

1. A cold producing apparatus comprising at least one heat exchanger, at least one inlet for high pressure medium communicating with said heat exchanger whereby the high pressure medium is cooled below the inversion temperature associated with said high pressure, at least one member in which the high pressure medium cooled in said heat exchanger is reduced in pressure, at least one reservoir in which the lower pressure medium can be brought into thermal contact with a place to be cooled or withdrawn in the liquid state from the apparatus, a duct system adapted for conducting away lower pressure medium through at least one heat exchanger, said reservoir in operation having a pressure which is lower than the pressure at which the medium is conducted out of said apparatus, at least one ejector in said member in which the high pressure medium cooled in said heat exchanger is reduced in pressure, each ejector being provided with a jet pipe and at least part of said cooled medium of high pressure being supplied to said jet pipes, the suction side of at least one ejector communicating with at least one of said reservoirs of the lower pressure, the outlet of said ejector communicating with said duct system whereby lower pressure medium can be conducted out of the apparatus, and said ejector having means for separating the peripheral layer formed on the walls of said jet pipe for the high pressure medium from the flow of said high pressure medium.

2. An apparatus as claimed in claim **1** and having an area of relatively low pressure, wherein said separating means is an annular recess in the wall of said jet pipe for the high pressure medium adjacent to the end thereof, and at least one conduit for communicating said annular recess with said relatively low pressure area.

3. An apparatus as claimed in claim **2** wherein at the location of said annular recess said jet pipe tapers in the direction of flow.

4. An apparatus as claimed in claim **1** further comprising a diffuser for conducting away the lower pressure meidum, and an inlet disposed between said jet pipe and said diffuser for receiving medium.

5. An apparatus as claimed in claim **4** having an area of relatively low pressure, wherein the separating means are formed by an annular recess in the wall of said jet pipe for said high pressure medium, said recess being located adjacent to the end of said jet pipe and communicating through a conduit with said area of relatively low pressure with respect to the pressure at said annular recess.

6. An apparatus as claimed in claim **5** wherein the diameter of said jet pipe at the area of said recess is considerably reduced as viewed in the direction of flow.

7. A cold producing apparatus comprising a medium supply under high pressure and at a temperature below the inversion temperature associated with said pressure, at least one ejector having a jet pipe to which at least part of said high pressure medium can be supplied, at least one heat exchanger through which the outlet of said ejector communicates therewith, and at least one pressure reducing device, said medium being reduced in pressure through said pressure reducing device, said jet pipe being provided with means for drawing off the peripheral layer of said high pressure medium formed on the walls of said jet pipe from the main body of said high pressure medium.

8. Apparatus for use with a medium dischargeable at a first high pressure from a source, comprising:

(a) a first heat exchanger for receiving and cooling the high pressure medium to a first temperature below its inversion temperature associated with that pressure;

(b) at least one ejector having (1) a first inlet for receiving from the heat exchanger cooled medium in a gaseous state, which medium is expandable in the ejector to a second intermediate temperature and pressure below that in said heat exchanger, (2) a suction inlet for pumping medium therein; and (3) an outlet through which expanded medium is dischargeable, some of said medium being returned to said source,

(c) at least one container having an inlet, and first and second outlets, and

(d) a choke means disposed between said ejector outlet and the container inlet, through which medium is further expandable to a third pressure below that of the second pressure,

(e) medium in vapor state being pumped from the container's first outlet to the suction inlet of the ejector, some medium from the ejector being dischargeable to said source, and the medium in said container providing cold for cooling a substance brought into thermal contact therewith,

(f) said ejector having (1) a jet pipe portion and (2) a diffuser portion through which medium flows and is expanded, said flowing medium tending to form a boundary layer adjacent the jet pipe's inner walls, and said ejector also having (3) means for separating said layer from said walls for improving the flow velocity therethrough.

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WILLIAM J. WYE, Primary Examiner

U.S. Cl. X.R.

62—514; 103—267