July 7, 1959 W. P. HENDAL 2,893,214

GENERATION OF COLD BY EXPANSION OF A GAS IN A VORTEX TUBE

Filed June 5, 1956 2 Sheets-Sheet 1

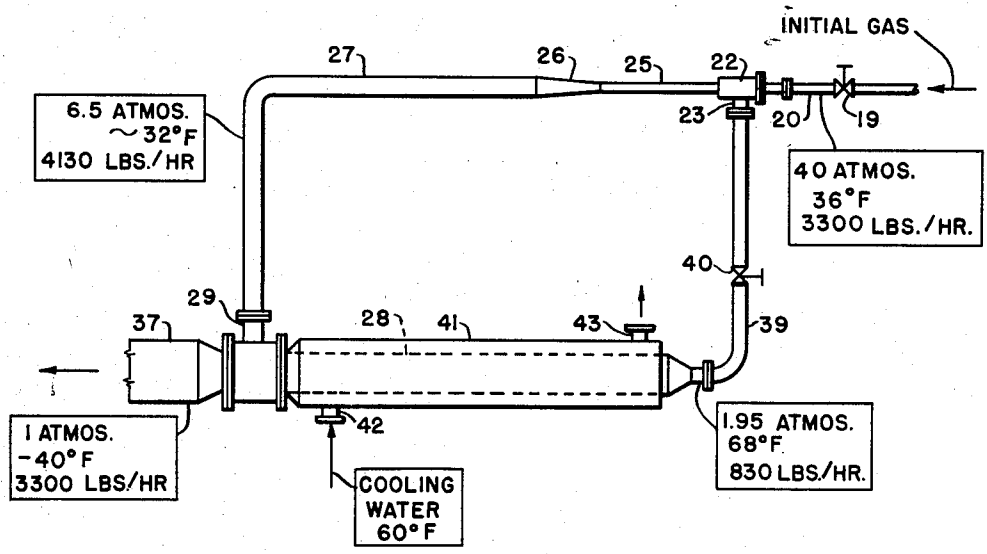



FIG. 1

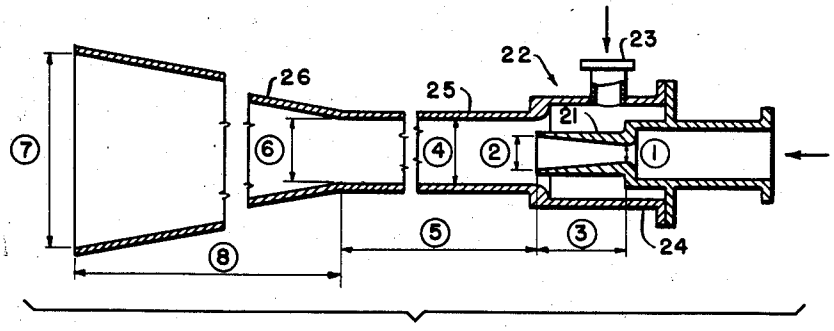



FIG. 2

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Filed June 5, 1956 2 Sheets-Sheet 2

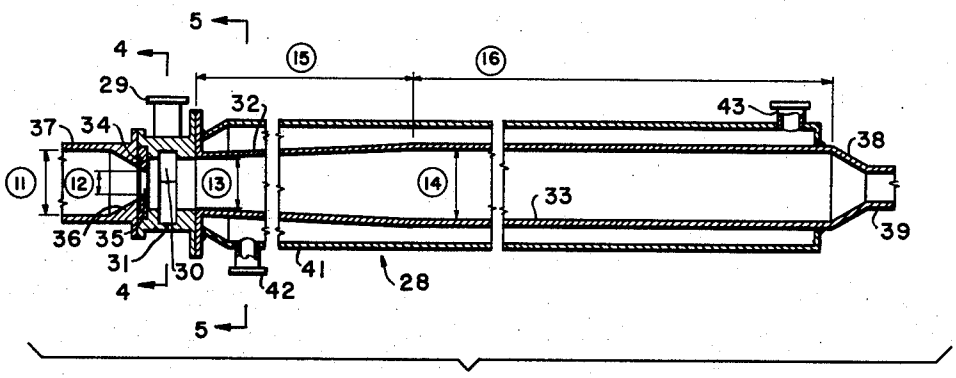



FIG. 3

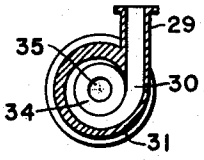



FIG. 4

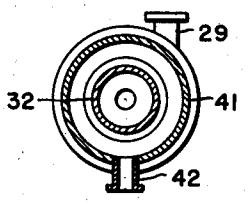



FIG. 5

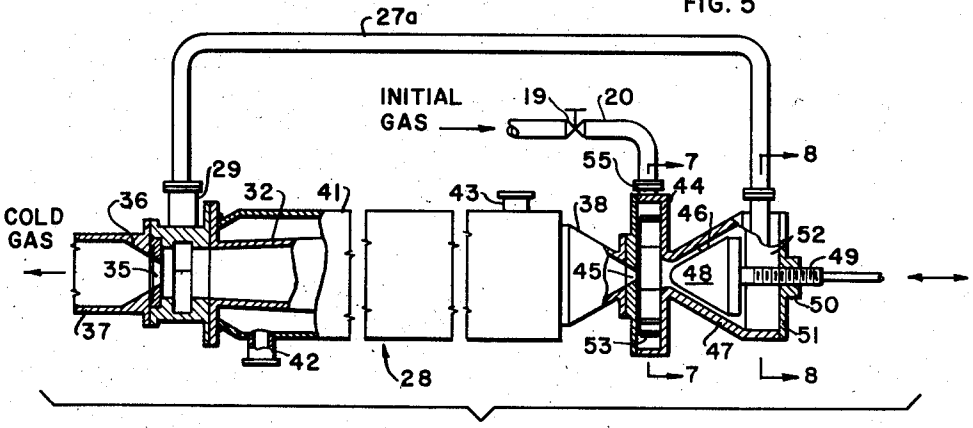



FIG. 6

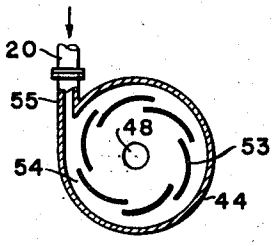



FIG. 7

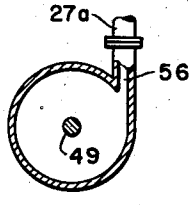



FIG. 8

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United States Patent Office 2,893,214 Patented July 7, 1959



2,893,214

# GENERATION OF COLD BY EXPANSION OF A GAS IN A VORTEX TUBE

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Application June 5, 1956, Serial No. 589,422

Claims priority, application Netherlands June 10, 1955

11 Claims. (Cl. 62—5)

This invention relates to a process for cooling a gas by expanding it within a vortex tube with gyratory motion, and to an improved vortex tube apparatus suitable for carrying out the said method. More particularly, the instant invention is concerned with the generation of cold in such a manner that there is produced a cold stream which has a low temperature and is large in relation to the volume of the initial feed stream, e.g., which may constitute the whole or most of the initial gas, and the invention is especially useful in instances where an initial gas is available in limited volume but at a considerable pressure.

In the case just mentioned the size of the available high-pressure stream is often insufficient to render the use of an adiabatic expansion engine attractive from an economic point of view. In such cases the vortex tube, also known as the Ranque tube or Hilsch tube, is often applicable because it uses no moving parts and is low in cost. Such a tube was described in U.S. Patent No. 1,952,281 to Ranque and a bibliography on vortex tubes, written by Curley and MacGee, Jr., was published in Refrigerating Engineering, vol. 59, 1951, pp. 166 and 191–193. As is set out in the said patent and the art noted in the bibliography, the vortex tube includes a chamber having the shape of a body of revolution, such as a cylinder, an inlet for admitting a feed gas under pressure with a gyratory motion, e.g., one or more inlet pipes situated near one end of the tube and disposed tangentially and in the same circumferential direction, and suitable outlets for discharging separately the gas fractions which appear within the tube as a peripheral stream and as a central core which fractions are, respectively, warmer and colder than the feed gas. Both fractions have pressures lower than that of the feed gas but the pressure of the fraction having the higher temperature exceeds that of the other fraction, in accordance with the Ranque effect. This phenomenon of the separation of the gas by expansion within a vortex tube into hot and cold fractions is hereinafter referred to as the heat-separation effect. This heat-separation effect results in the heating of at least a part of the vortex tube wall, unless cooling is applied thereto.

Various outlet arrangements are possible. The cold gas fraction is usually discharged through an orifice situated at the tube axis in a plate or end wall near and to one side of the tangential inlet; the tube extends to the other side of the inlet for a distance which is usually large in relation to the tube diameter, e.g., 6 to 30 diameters, lengths of 18 to 20 diameters being common, and the latter side, also known as the hot end, has a discharge opening for the hot gas fraction, situated either near the periphery or near the axis, which is conveniently provided with a throttle valve for regulating the magnitude of the stream discharged at the hot end. In certain arrangements, using the so-called uniflow principle, the outlets for the cold and hot fractions are arranged concentrically at the same end, the cold fraction passing out near the axis. Finally, the cold-gas outlet may be a small annular opening surrounding the tube axis instead of a central orifice. The dimensions and shape of the tube may vary within wide limits according to the conditions under which the vortex tube has to operate; suitable dimensions are readily determined experimentally in accordance with the principles and examples given in art noted in the above-mentioned bibliography.



It is known that the temperatures of the discharged gas fractions can be varied by the throttling one or the other, the control being usually applied to the hot-fraction outlet. The effect on temperatures is indicated by the graphs presented by Sprenger on page 295 of Zeitschrift für Angewandte Mathematik und Physik, vol. II (Basel, Switz., 1951). Lowest exit temperatures can, however, be attained only when the volume of the cold fraction is kept small, e.g., about 30–35% of the feed gas, while the greatest cooling effect (product of the quantity of the cold fraction and its temperature drop) is attained when the cold fraction is about 60%. An increase in the permissible volume of the cold fraction and/or a further reduction in the temperature can be attained by cooling the enclosing wall of the vortex tube, e.g., by applying cooling water, as described and claimed in my earlier, copending patent application, Serial No. 468,487, filed November 12, 1954.

The extent of cooling attainable in a vortex tube increases with the ratio of the inlet pressure of the feed gas ($p_i$) to the expansion pressure outside of the vortex tube ($p_o$). However, as is explained hereinafter, increased cooling is attained practically only up to a limiting ratio because further increase in the inlet pressure $p_i$ does not produce a further increase in the inlet velocity to the vortex tube when that velocity is at or close to the local speed of sound. When the cold gas is to be utilized at a pressure so low that the ratio thereto of the available inlet pressure is higher than this limit, an additional expansion or throttling of the gas must be performed, and in the usual case followed in the prior art represents a waste of energy because no useful refrigeration is achieved thereby.

It is also known to attain lower temperatures in the final cold gaseous effluent by expanding the gas in stages when an initial gas at a suitably high pressure is available. Thus, as shown in the German Patent No. 858,260, and in the Swiss Patent No. 276,405, the cold gas fraction discharged from each vortex tube before the last of the series is charged as feed gas into the next vortex tube through the tangential inlet nozzle thereof. Since a part of the gas is abstracted in each vortex tube as a hot gas fraction, the volume of the final cold gas is always significantly less than that of the feed stream; the attempt to augment the volume of the final cold gas by recirculating the hot gas fraction to the inlet of a prior vortex tube, in accordance with the aforesaid Swiss patent, requires the use of extraneously powered compressors, leads to a complicated recycling system which is difficult to regulate, the progressively lower temperature levels of the tubes make it difficult to generate the maximum cold, as is explained further hereinafter. In contrast to these limitations, it is often the case that the quantity of the initial, high-pressure gas is so limited that recovery of substantially all the gas in the final cold effluent at a low temperature is desired, whilst, moreover, the cold load is such that it is not economical to employ extraneously powered compressors; moreover, it is often desirable to avoid the use of all equipment having moving parts that may require maintenance.

It is, therefore, an object of the invention to provide an improved method and apparatus for expanding a gas which is initially under pressure within a vortex tube so as to produce a cold gas stream the volume of which is large in relation to that of the initial gas and wherein a

highly effective reduction in the temperature of the gas is attained.

A further object is to expand the gas as outlined in the preceding paragraph while avoiding the use of equipment utilizing moving parts or consuming extraneous power, whereby the total energy supplied to the system is contained in the feed gas.

Further objects will become apparent from the following description.

In summary, according to the invention the feed gas stream is charged with a gyratory motion into a vortex tube wherein it is divided by the heat-separation effect into hot and cold fractions, these fractions are discharged separately, and gas from the discharged hot fraction is recompressed and thereafter expanded in a vortex tube. According to one novel feature the initial, high-pressure gas is, prior to entry into the vortex tube, passed as the driving fluid through a fluid-actuated compressing device, preferably one having no moving parts, such as a jet pump or a diffuser, whereby the feed gas is partially expanded before being fed into the vortex tube, and the gas of the hot fraction discharged from the vortex tube is compressed within the said compressing device. Cooling is preferably applied to the said gas of the hot fraction prior to the subsequent expansion thereof in a vortex tube, e.g., while still within the vortex tube within which it is first formed, as by applying a coolant to the tube wall; in this case the gas is discharged at a reduced temperature which may be about the same as that of the initial gas, but such gas will, nevertheless for convenience, be herein called the "hot gas fraction," to distinguish it from the other gas fraction which always has a lower temperature. According to still another feature of the invention, the recompressed gas is expanded within the same vortex tube as that from which it was discharged just prior to recompression, being, for example, commingled with the initial gas in the compression device when the latter takes the form of a jet pump or diffusor; however, the invention is not limited to such commingling within the compressing device. For best advantage, these features are applied concurrently.

The invention will be described in greater detail in connection with the accompanying drawings forming a part of this specification and showing certain specific embodiments by way of illustration, wherein:

Figure 1 is a flow diagram of one embodiment of the invention;

Figure 2 is a longitudinal sectional view through the jet pump of Figure 1;

Figure 3 is a longitudinal sectional view through the vortex tube of Figure 1;

Figures 4 and 5 are transverse sectional views taken on the correspondingly numbered section lines of Figure 3;

Figure 6 is a flow diagram of a second embodiment of the invention, the vortex tube and diffusor being shown in longitudinal section; and

Figures 7 and 8 are transverse sectional views taken on the correspondingly numbered section lines of Figure 6.

The phenomenon of the heat-separation effect and the influence thereon of the pressure relations and temperature levels are basic to the invention. Because the specification and claim-definition necessitate an understanding of this effect, a description thereof will be set forth by way of introduction to the detailed embodiments.

A theoretical explanation of the heat-separation effect is based on the fact that there is evidently a transfer of energy from the gas at the central part of the tube to the gas near the confining wall. This transfer of energy increases the temperature of the outer gas layers leaving the tube as the hot gas fraction, e.g., through the throttle valve, and lowers the temperature of the inner gas layers escaping as the cold gas fraction through the orifice.

Closer examination shows that there is first a transfer of energy caused by the friction between the layers of the rotating gas colum which are in the neighbourhood of the tube axis and the layers nearer to the wall of the tube. As the inner layers rotate at a higher angular velocity than the outer layers, the inner layers tend to accelerate the outer ones by friction, the result being a transfer of kinetic energy in a direction outward from the tube axis. A second, more important contribution to the temperature effect is the transfer of energy caused by turbulent currents in the radial pressure area of the rotating gas column. Owing to the strong centrifugal forces there is a considerable difference in pressure between the inner and outer layers. As a result of the said turbulent currents a quantity of gas will move outwards and be compressed more or less adiabatically, as a result of which the temperature of the outer gas will rise. A quantity of gas moving in the opposite direction will expand and become cooler. In this way the turbulence will cause a temperature distribution in a radial direction.

According to this theory, the Ranque effect is governed by three variables, viz.:

(1) The effect is dependent on the absolute temperature (T.) of the feed gas introduced.

(2) The effect is dependent on the ratio of the inlet pressure of the feed gas ($p.$) to the expansion pressure outside of the tube ($p$); this pressure ratio

$$\frac{p.}{p}$$

is hereinafter termed the effective pressure ratio.

(3) The effect is dependent on the ratio between the specific heat at constant pressure ($c_p$) to that at constant volume ($c_v$) of the gas used.

In order to compare quantitatively the effect of vortex tubes of different designs, when the tubes in question are used as a cooling apparatus, note is taken of the ratio between the decrease in the enthalpy of the quantity of gas leaving the vortex tube as cold gas and the decrease in the enthalpy which would be theoretically reached when the whole amount of gas were allowed to expand isentropically while carrying out external work. This ratio is hereinafter termed the cooling effect; it may be considered as the efficiency of the vortex tube.

In the case of an ideal or pratically ideal gas such as air (wherein the ratio

$$\frac{c_p}{c_v}$$

is constant and there is a very small or no Joule-Thomson effect), the above-mentioned cooling effect or efficiency may be expressed as follows, based on a calculation of this ratio:

$$\eta_r = \frac{\mu \Delta T}{T_o\left[1-\left(\frac{p_o}{p}\right)^{\frac{1-k}{k}}\right]}$$

in which:

$\mu$ = the separation coefficient, that is, the ratio of the quantity of the cold gas fraction to the total quantity of gas;

$\Delta T$ = difference in temperature between the feed gas and the cold gas leaving the vortex tube;

$\eta_r$ = the cooling effect or efficiency factor of the refrigeration;

$T.$ = absolute temperature of the feed gas;

$p$ = expansion pressure outside of the vortex tube;

$p.$ = pressure of the feed gas supplied; and

$k = \frac{c_p}{c_v}$

If the above formula is applied with a value of 100 atm. abs. for the pressure $p.$, other conditions being unchanged, in particular with a constant cooling effect

$\eta_r$ and a constant fraction $\mu$ of cold gas, and expansion to a pressure $p$ of 1 atm. abs., a reduction of temperature is calculated which is 50% higher than that reached when the value of the pressure $p.$ is 10 atm. abs., again with expansion to 1 atm. abs. The latter feed pressure ($p.$=10 atm. abs.) is of the order of magnitude which is commonly used in tests with vortex tubes. However, it is usually found in practice that an effective pressure ratio

$$\frac{p.}{p}$$

greater than approximately 20 does not give rise to any appreciably better temperature effect. This anomaly between theory and practice is ascribed, among other causes, to the fact that from a given high pressure the gas in the narrowest cross section of the tangential inlet nozzle acquires a velocity which at its maximum equals the local speed of sound. It is a scientific fact that the velocity of the gas in such a nozzle does not exceed this speed limit, despite the use of higher pressures.

For cooling gas which has a high initial pressure and which it is desired to discharge from the vortex tube at not too high a pressure, the gas should be brought to such a desired feed pressure, e.g. by throttling before admission to the vortex tube, that the effective pressure ratio is the normal one for the vortex tube. In this way, however, a considerable amount of energy is lost.

This drawback can be overcome, as is shown in Fig. 8 of the German Patent No. 858,260, by allowing the gas to expand in stages in vortex tubes connected in series, the partly expanded and cooled gas being led from the first vortex tube to the inlet nozzle of the second vortex tube, etc. As each of the vortex tubes is operated in such a manner that the fraction of cold gas discharged is approximately 0.6–0.7 of the feed gas, approximately 40–30% by volume of gas is drawn off at the hot end—which is the most favorable value for a maximum cooling effect—it is self-evident that there is a loss of 40–30% in each vortex tube of the series, leading to a loss of 78 to 65% when three tubes are used. By using a complicated recycling system, in which the hot gas fraction discharged from one tube is cooled between two vortex tubes before it enters another vortex tube, this loss can be reduced. It is, however, evident that such a solution is too complicated to be technically attractive. Moreover, with a series arrangement of the vortex tubes a progressively lower temperature is reached, which is often a drawback when the requirement is to be made that as much cold as possible is to be generated (i.e. $\mu\Delta T$ is to be as large as possible), while at the same time the temperature may not be too low (i.e. $\Delta T$ is not to exceed a given value). These requirements may arise when an object to be cooled by the cooled gas cannot tolerate too low a temperature, as this may cause undesirable material stresses. It is clear that in such a case the connection according to the German patent cannot be used.

One encounters even more of a drawback to the series arrangement when only a limited quantity of initial gas under high pressure is available, so that the losses in gas in the form of warm gas must be restricted as much as possible.

It has now been found that the foregoing difficulties can be avoided in accordance with the invention.

Referring to Figures 1–4 in detail, there is shown an arrangement embodying all of the several features indicated in the earlier summary of the invention and employing a jet pump. An initial gas, which may have a high pressure, such as between 25 and 150 atmospheres absolute, and cooled if appropriate to such temperature as is conveniently attainable by heat exchange with available, usually non-refrigerated coolants, e.g., 55 to 100° F., is admitted from a source, not shown, through a valve **19** and supply pipe **20** to the convergent-divergent nozzle **21** which forms the pressure inlet of a jet pump



**22** having, further, a suction inlet **23** by which gas to be compressed is admitted. Expansion through the valve **19** may be used to precool the gas. The casing **24** of the jet pump is connected to a mixing tube **25** into which extends the end of the nozzle **21** and wherein the initial feed gas is commingled with the gas admitted through the suction inlet. The resulting mixture flows thence through a diverging tube **26** into a pipe **27**. In flowing through the jet pump the initial gas is partly expanded, resulting in a temperature reduction, and the gas admitted at the suction inlet is compressed.

The combined gaseous streams are admitted to a vortex tube **28** through a tangential inlet nozzle **29** the end **30** of which is advantageously joined to the confining wall of the tube by a spiral wall **31** as shown in Figure 4, so as to center the resulting gas vortex at the axis of the tube. The tube is shaped internally as a surface of revolution, and may include a slightly divergent section **32** joined to a cylindrical section **33**. The divergent section **32** preferably has an angle of divergence (i.e. the apex angle of the cone of which the section is a fraction) of between about 2° and 6° and is the subject matter of my application Serial No. 589,423, filed concurrently herewith. An orifice disc **34**, mounted near the inlet nozzle, has an orifice **35** situated at the central axis of the vortex tube for the discharge of the cold, central part of the gaseous vortex forming the cold fraction. The latter flows through a short diverging section **36** into a discharge pipe **37**. The hot end of the tube has a convergent section **38** by which the hot fraction is led to a discharge pipe **39** leading to the suction inlet **23** and having a throttle valve **40** interposed therein. It is understood that this valve may be placed as desired, e.g., within the vortex tube. The tube is jacketed as shown at **41**, whereby a cooling liquid such as water can be circulated through the inlet and discharge nozzles **42** and **43** and in contact with the confining wall sections **32** and **33** for cooling these walls intensively. This cools the hot gas fraction, which moves as a peripheral stream within the tube in contact with the confining wall sections. This cooling may be sufficiently intensive to cool the discharged hot gas fraction approximately to the temperature of the initial gas. By making the tube sufficiently long the gas can be made to approach closely the temperature of the cooling liquid.

## EXAMPLE

Referring to Figure 1, gas, e.g., nitrogen, having an initial pressure of 40 atmos. abs. and a temperature of 36° F. (which may, for example, be obtained by expansion through the valve **19** from 120 atmos. and 68° F.) is admitted continuously at the rate of 3,300 lbs./hr. through pipe **20** as the driving fluid into the jet pump **22**, thereby effecting partial expansion and cooling. It and recycle gas admitted at **23** are discharged to the pipe **27** at the rate of 4,130 lbs./hr. at a pressure of 6.5 atmos. abs. and a temperature of about 32° F., and charged through the nozzle **29** to the vortex tube **28**, which is cooled intensively by water circulated through the nozzles **42** and **43** at 60° F. at a rate of 530 to 790 gals./hr. Within the vortex tube the gas is divided into two fractions, respectively a cold fraction at the center which is discharged to the pipe **37** at a pressure of 1 atmos. abs. and a temperature of −40°, and a hot fraction adjoining the tube wall which is discharged to the pipe **39** at a pressure of 1.95 atmos. abs. and a temperature of 68° F. when the valve **40** is adjusted to make the latter fraction flow at the rate of 830 lbs./hr. The cold fraction is discharged at the rate of 3,300 lbs./hr.

The significant conditions are indicated in the boxes on Figure 1. The chief dimensions of the jet pump and the vortex tubes, indicated in Figures 2 and 3, for the above example are given in Table I and Table II, respectively, in millimeters and square millimeters.

*Table I*

Chief dimensions of jet pump **22**:

| | | |
|---|---|---|
| (1) | Diameter of nozzle neck ____mm__ | 9.40 |
| (2) | Diameter of discharge end of nozzle ____mm__ | 16.0 |
| (3) | Length of diverging section of nozzle ____mm__ | 47.0 |
| (4) | Diameter of mixing tube____mm__ | 26.0 |
| (5) | Length of mixing tube ____mm__ | 315 |
| (6) | Diameter of entrance of diverging tube ____mm__ | 26.0 |
| (7) | Diameter of outlet of diverging tube ____mm__ | 64.0 |
| (8) | Length of diverging tube ____mm__ | 190 |

Chief dimensions of vortex tube **28**:

| | | |
|---|---|---|
| (11) | Diameter cold fraction discharge pipe ____mm__ | 76 |
| (12) | Diameter discharge orifice ____mm__ | 44.5 |
| (13) | Diameter of beginning of diverging section **32** ____mm__ | 75 |
| (14) | Diameter of end of diverging section **32** (and of cylindrical section **33**) __mm__ | 112.5 |
| (15) | Length of diverging section ____mm__ | 600 |
| (16) | Length of cylindrical section ____mm__ | 2250 |
| (17) | Area of inlet nozzle **30** ____sq. mm__ | 387 |

If the cooling capacity of the above equipment is compared with a simple cooled vortex tube, the desired pressure ratio between the initial and final pressure

$$\frac{(p.)}{(p)}$$

being adjusted by throttling the high-pressure gas, the process according to the invention results in an increase in the cooling capacity of at least 25%.

In the embodiment shown in Figures 6–8, the vortex tube **28** is constructed as was described for Figures 1–5, and like reference numbers denote like parts. The fluid-driven compressing device is in this instance a diffusor, constructed similarly to that shown in the British Patent 648,980. It includes a whirl chamber **44** disposed coaxially with the vortex tube and communicating therewith through a central suction opening **45** formed in one chamber wall; a similar opening in the opposed chamber wall communicates with a diverging, annular diffusion channel **46** defined between a confining wall **47** and an axially disposed diffusing body or deflector **48**. The body **48** and wall **47** have complementary surfaces of revolution, e.g., frusto-conical as shown, while the apex of the said body is rounded. The body is axially reciprocable by means of a threaded support rod **49** and an internally threaded bushing **50** carried by the rear wall **51** of the pressure-recovery chamber **52** with which the wide end of the diffusion channel communicates. The periphery of the whirl chamber is provided with one or more tangential inlets, such as channels defined between vanes **53**; the arrangement of these vanes is preferably such that the gas enters with a rotary movement in the same direction as the movement of the gas in the vortex tube. These inlets are supplied from an annular channel **54** to which the initial gas is supplied from the pipe **20** through an inlet nozzle **55**. The chamber **52** has an outlet **56** which may, if desired, enter tangentially as shown, which is connected by a pipe **27***a* to the vortex tube inlet nozzle **29**.

Operation of the embodiment of Figures 6–8 is as follows: Initial gas such as nitrogen under high pressure, e.g., 150 atmos. abs., is supplied via the pipe **20**, nozzle **55** and the tangential inlets between the blades **53** to the periphery of the whirl chamber **44** with a gyratory motion, resulting in the formation of a vortex in which the gas rotates with increasing angular velocities and lower pressures toward the axis. The gas is thereby expanded considerably and pressures below those of the hot gas fraction discharged from the vortex tube e.g., as low as 1 atmosphere absolute, are generated at the center. This creates a suction effect on the hot gas fraction, which is drawn into the whirl chamber through the suction opening **45** from the exhaust section **38**, wherein the absolute pressure is, e.g. about 2 atmospheres. This provides an adequate suction head for discharging the hot gas fraction from the vortex tube. The commingled gases move with a gyratory motion through the annular diffusion channel **46**, wherein the rotational energy is largely converted into pressure energy, whereby the pressure is raised, e.g., to 10 atmos. abs., upon entry into the pressure-recovery chamber **52**. From the latter the gases flow via outlet **56** and pipe **27***a* to the inlet nozzle **29** of the water-cooled vortex tube **28**, wherein the combined gases are expanded and separated into hot and cold fractions. An amount equal to that admitted from the pipe **20**, e.g., 80% of the gas admitted through the nozzle **29**, is discharged at **37** as the cold fraction at a low pressure, e.g., 1 atmos. abs., the remainder being recirculated to the diffusor. The recirculation rate can be controlled by altering position of the body **47** to vary the size of the diffusion channel **46**. A 25% increase in the quantity of cold, in terms of frigories (negative calories) is attainable in comparison with a simple cooled vortex tube.



I claim as my invention:

1. A method of producing cold in a gas stream which is initially under pressure comprising the steps of flowing said gas as the driving medium through a fluid-actuated compressing device and thereby effecting a first expansion; further expanding the gas in a vortex tube means by admitting the gas thereto with a gyratory motion and effecting a separation of the gas into a hot fraction in contact with the wall of said tube as a peripheral stream and a cold fraction rotating within said peripheral stream; separately discharging said fractions from the vortex tube means; feeding gas discharged in the hot fraction to said compressing device and compressing it therein; and expanding the resulting compressed gas in said vortex tube means by admission in the compressed state with gyratory motion to effect a separation into hot and cold parts.

2. Method according to claim 1 wherein the gas of said hot fraction is cooled prior to admission in the compressed state into the vortex tube.

3. Method according to claim 2 wherein the gas of said hot fraction is cooled while forming said peripheral stream by applying a cooling medium to said tube wall.

4. Method according to claim 2 wherein said first and latter vortex tubes are the same and the compressed gas is expanded within the vortex tube from which it was discharged as the hot gaseous fraction.

5. Method according to claim 4 wherein said compressing device is a jet pump, said initial gas being passed therethrough as a jet and said gas of the discharged hot gaseous fraction being commingled with said jet.

6. Method according to claim 4 wherein said compression device is a diffusor having a whirl chamber connected to a pressure-recovery chamber, said initial gas being admitted into the diffusor with a gyratory motion into an outer part of said whirl chamber to form therein a gas vortex having a low-pressure central part, the said hot fraction discharged from the vortex tube being drawn into said gas vortex in the whirl chamber at the said central part thereof, and the rotational velocity of the resulting mixed-gas vortex being recovered as pressure by flow into said pressure-recovery chamber.

7. Vortex tube apparatus for producing cold in a gas stream which is initially under pressure comprising: a fluid-actuated compressing device having a pressure inlet for admitting said initial gas stream as the driving medium, a suction inlet for a gas to be compressed, and at least one outlet; a vortex tube having an inlet for admitting gas with a gyratory motion to separate gas into coaxially situated hot and cold fractions by the heat-separation effect and individual outlets for the discharge

of the said fractions; conduit means interconnecting the said outlet for the hot fraction to the suction inlet of the compressing device; conduit means for flowing both said initial gas and the compressed gas from the outlet of the compressing device to said inlet of the vortex tube; and means for cooling, prior to the return to the vortex tube, the gas of said hot fraction.

8. A vortex tube apparatus according to claim 7 wherein said means for cooling the gas of the hot fraction includes flow means for circulating a cooling fluid about the enclosing wall of said vortex tube, whereby said gas is cooled prior to discharge.

9. A vortex tube apparatus according to claim 7 wherein said compressing device is a jet pump.

10. A vortex tube apparatus according to claim 7 wherein said compressing device is a diffusor having a whirl chamber with a tangential inlet constituting said pressure inlet, a central suction inlet, and a pressure-recovery chamber connected to said whirl chamber through a channel suitable for recovering pressure.

11. Vortex tube apparatus for producing cold in a gas stream which is initially under pressure comprising: a vortex tube adapted to separate a gas into coaxially situated hot and cold fractions by the heat-separation effect including a tangential inlet and individual outlets for the resulting hot and cold fractions, said outlet for the



hot fraction being disposed coaxially with the tube for the discharge of the gas thereof with a whirling motion; means for cooling the outer wall of said vortex tube; a whirl chamber in the form of a flat cylindrical box disposed substantially coaxially with said outlet for the hot fraction and having an axial inlet connected to said last-mentioned outlet and, near the periphery, one or more tangential inlets for the admission of said initial gas stream with a circumferential velocity component in the same direction as the rotation of the gas in the vortex tube; a diffusor including a pressure-recovery chamber and an annular diverging diffusion passageway disposed coaxially with said whirl chamber communicating therewith at the central part thereof; and conduit means for conducting gas from said pressure-recovery chamber to the said inlet of the vortex tube.

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