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VORTEX TUBE WITH INTERNAL COOLING

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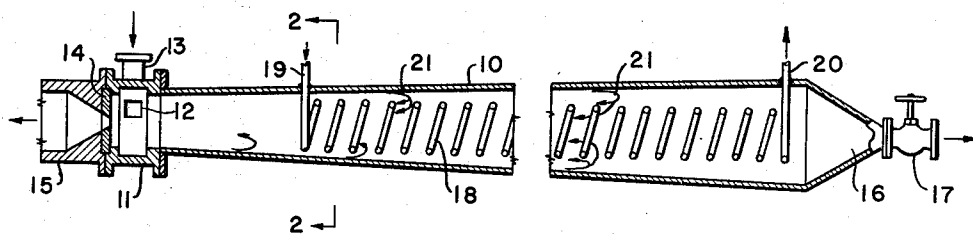


FIG. 1

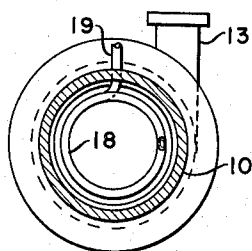


FIG. 2

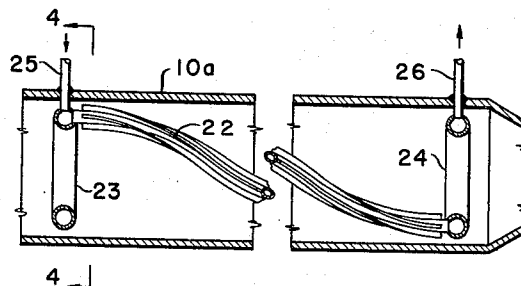


FIG. 3

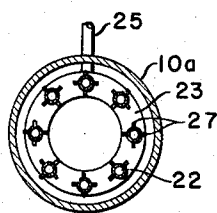


FIG. 4

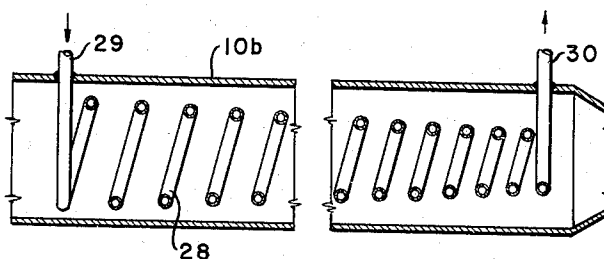


FIG. 5

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VORTEX TUBE WITH INTERNAL COOLING

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This invention relates to a method of lowering the temperature of a gas stream by expansion in a vortex tube and to an improved vortex tube. In such a process the gas stream is expanded with gyratory motion about the axis of the vortex tube to separate the gas into hot and cold fractions, and gas is discharged continuously in a manner dependent upon the particular purpose to which the process and tube are applied. Thus, the two gas fractions may be discharged from the tube in any desired ratio from zero to infinity; in other words, two gas streams having different temperatures or only one gas stream may be discharged from the tube. The utility of discharging only one stream will become apparent from the sequel. Although not restricted thereto, vortex tubes find particular utility for the production of cold gas streams from gas which occurs initially at superatmospheric pressure, especially when the refrigeration load in a given process wherein the cold gas is to be utilized is so small or intermittent that more elaborate machinery, such as adiabatic expansion engines, are not commercially attractive.

A general description of the vortex tube and literature references are presented in U.S. Patent 2,861,431, which disclosure is incorporated herein by reference. As noted in that patent, it is known to cool the chamber wall externally along that part of its length where the heat separation effect occurs, e.g., by an external cooling jacket through which a coolant is flowed, or by contact with the cold gas fraction formed in an outer, concentric vortex tube. It has been further proposed to cool the chamber wall internally by a cold liquid film which flows along the inner surface of the vortex tube wall; see British patent specification No. 762,563. By these expedients heat is abstracted from the hot gas fraction, largely during the heat separation effect.

It is the object of this invention to improve further the efficiency of the vortex tube for generating a cold gas.

According to the invention it was found that the efficiency may be significantly increased by cooling the gas inside the vortex tube, radially inwardly from the tube wall, by heat exchange with a cold body in a zone displaced axially from the inlet zone into which the gas is admitted with a gyratory motion.

The heat separation effect occurs principally at and near to the inlet zone. For convenience the region in which a significant heat separation occurs is herein called the first region. Beyond the first region, toward the hot end of the tube, is a region, herein for convenience called the second region, wherein the heat separation effect does not occur or wherein it occurs only to a slight extent. The cooling of the gas by heat exchange according to this invention is preferably effected in the second region.

In the preferred arrangement of the vortex tube the first region is mechanically unobstructed, i.e., it is empty save for the gas, and the cooling in the second region

is effected by a hollow body mounted coaxially within the vortex tube in spaced relation to the tube wall, this body being preferably axially elongated. The body may be cooled in any suitable manner, as by circulating a coolant therethrough.

It is, however, also possible to locate the cooling body in the first region or to use a cooling body of such length that it extends through both regions but preferably does not extend into the inlet zone itself. In this case the cooling body, or at least the part thereof which lies within the first region, should be so designed that the gas flow patterns requisite for the heat separation effect are not prevented; in particular, it should be possible for the gas to flow radially in the first region from the periphery to the central axis of the tube. The cooling body should advantageously be displaced axially from the inlet zone a sufficient distance to avoid disturbance of the flow patterns which are necessary for efficient attainment of the heat separation effect. In general, the displacement should be at least as great as the diameter of the vortex tube and displacements of two or more diameters are usually preferred. In many cases it is advisable to utilize a cooling body which permits such radial flow also in the second region.

To enable the rotating gas to flow radially toward the central axis and there constitute a cold gas stream which flows toward the cold-gas outlet, the cooling body is provided with lateral passages, such as orifices, slits, or the like, through which the gas may flow. For example, the slits may be situated in planes at right angles to the vortex tube axis or may be helical, preferably in conformity to the gas flow. The passages through the cooling body are preferably stream-lined, so that the flow lines of the original flow pattern (i.e., the flow pattern that would prevail locally if the cooling body were absent) remain intact as much as possible and the flowing gas meets the least possible resistance.

The cooling body may consist of a spiralized cooling tube having the overall shape of a body of revolution, such as a cylinder or cone. The cooling tube may be in the shape of a multiple spiral and, if desired, the windings may be arranged at such wide intervals that a helical passage is formed between successive turns for the radial flow of the gas. The pitch of the windings is preferably such that it is at least approximately the same as the pitch of the stream of rotating gas contiguous thereto. This insures that the rotation of the gas is retarded as little as possible. The pitch of the above-mentioned helical slits is preferably similar.

The cooling body may also be shaped to provide two coaxial walls shaped as surfaces of revolution, e.g., cylindrical, conical, or the like, to define therebetween an annular space through which the refrigerant is passed. In order to improve heat transfer, these surfaces of revolution, as well as the above-mentioned tubes, may be provided with projections, such as ribs on the inside and/or the outside, where the cooling body is in contact with the gas to be cooled. Such projections may, however, be used only in the second region of the vortex tube unless they extend longitudinally and are stream-lined. Also, in this embodiment passages, for example slits, may be formed in the walls and bounded by connecting walls to permit gas to flow in a radial direction in isolation from the refrigerant.

The gas moving from the periphery to the center line of the tube flows thence axially to the cold-gas outlet, which is situated at or near the central axis, usually at the end of the first region remote from the second region. Since the rotating gas flows longitudinally along the surface of the cooling body it is cooled en route, either while flowing toward the hot end near the pe-

riphery or toward the cold gas outlet near the axis, or, in some instances, during both flows; it is also cooled while flowing radially through the passages. It is preferred to locate at least a part of the cooling body sufficiently near to the central axis to effect cooling of the gas which flows near the central axis. The gas flowing near the periphery may be also cooled by a part of the cooling body, e.g., by the radially outer surface thereof or by a separate, concentrically mounted larger coil.

This method of operating a vortex tube increases the efficiency by up to 40-45% when compared to the known externally cooled vortex tube or the vortex tube which is cooled internally with a liquid film. This is due only in part to the fact that the cooling capacity is used more efficiently, since in the known vortex tube cooling takes place only at the periphery of the tube so that the gas drawn off at the hot end is also cooled. This latter cooling, however, makes no useful contribution to the generation of cold; it would be sufficient only to cool the return gas, i.e., that part of the hot gas ultimately contributing to the quantity of cold gas withdrawn (viz., the part of the gas that is heated when expanded in the vortex tube but leaves the tube but leaves the tube via the cold-gas outlet). In the present method of cooling the cooling body abstracts heat principally from the part of the hot gas which is ultimately discharged through the cold-gas outlet.

Increased efficiency is further caused by improved heat transfer. The conventional way of cooling is, in particular, ineffective in this respect in that the refrigeration effect of the coolant is poorly transferred to such gases as return to the cold-gas outlet, for the peripheral layer of gas flowing toward the hot end has a great heat-insulating effect. According to the new method, however, the gas which returns to the cold-gas outlet, moving first from the more peripheral parts of the vortex tube to the center line of the tube, is effectively cooled before it contributes to the quantity of drawn-off cold gas.

The invention will be further described with reference to the accompanying drawing forming a part of this specification and showing, by way of example, certain preferred embodiments, wherein:

Figure 1 is a longitudinal section through a vortex tube according to the invention;

Figure 2 is a transverse section taken on the line 2-2 of Figure 1, drawn to an enlarged scale;

Figure 3 is a longitudinal section of a part of a vortex tube having a cooling body according to a modified design;

Figure 4 is a transverse section taken on the line 4-4 of Figure 3; and

Figure 5 is a longitudinal section of a part of a vortex tube having cooling body according to a third design.

Referring to Figures 1 and 2, the apparatus comprises a tube 10 connected to an inlet section 11 to which the feed gas is admitted tangentially through an inlet 12 from a nozzle 13. An orifice disc 14 is mounted at one end of the inlet section and has a central orifice which constitutes the cold-gas outlet and through which the cold gas is discharged into a conduit 15. The tube may have any suitable length, e.g., 6-30 diameters, lengths of 10-20 diameters being common. The tube 10, known as the hot end of the vortex tube apparatus, has a hot-gas outlet 16 which is controlled by a throttle valve 17. The tube 10 may be externally cooled by a jacket, as described in the aforesaid U.S. Patent No. 2,861,431, although this is not essential. It may be noted that an axial hot-gas outlet 16, as shown, is applicable particularly to long tubes, e.g., those more than 20 diameters in length. When shorter tubes are used it is advantageous to provide a transverse baffle within the tube having a peripheral clearance with respect to the tube wall so as to permit only the outer, warmer gas to pass; this arrangement being shown in the aforesaid patent, it is not shown in the instant drawing. The tube 10

may diverge toward the hot end, as shown, although the invention may also be used with cylindrical tubes.

According to the invention the tube 10 contains a cooling body, having in this embodiment the form of a helical coil 18 the turns of which are axially spaced to permit free passage of gas from the tube wall toward the central axis. The cooling coil is advantageously mounted at least partly within the diverging part of the tube. The diameter of the coil is small enough to provide a mechanically unobstructed path between it and the tube wall, yet large enough to provide a similar axial path within it. The coil diameter is generally between 0.2 and 0.9 of the diameter of the tube 10 and, in most cases, between 0.5 and 0.7 of the latter diameter. Coolant, such as air, water or brine is circulated through the coil from an inlet pipe 19 and is discharged through an outlet pipe 20. To promote most intense cooling near the cold-gas outlet it is preferred to admit the fresh coolant near the cold end of the vortex tube, as shown.

The pitch and screw direction of the helix are advantageously such as to interfere as little as possible with the normal gas flow patterns, and will be influenced by the operating conditions, particularly the velocity and rate of gas flow and the diameter of the helix. As regards the diameter, it may be noted that the rotating gas passing through the tube 10 flows toward the hot end near the tube wall and that return gas flows toward the cold end near the central axis. The latter flow consists of gas which flows radially inwards, as shown by the arrows 21. If the helix diameter is sufficiently large to be surrounded by the gas flowing toward the hot end it will have one screw direction, while if its diameter is sufficiently small to be surrounded by gas flowing in the other direction it will have the opposite screw direction. While either arrangement may be employed, it is preferred to make the helix diameter so small as to be surrounded by the inner gas stream and to conform it to the movement of the gas flowing toward the cold end.

When the vortex tube is to be used at very low temperatures, as when the feed gas is already at a low temperature and the vortex tube is used to effect a further lowering of the gas temperature, it is desirable to use a refrigerated coolant, such as liquid ethylene or propane. It should be noted, however, that the coolant is generally supplied at a temperature above that of the cold gas discharged through the conduit 15 and usually not colder than the feed gas.

In operation, the feed gas admitted via the tangential inlet 12 rotates about the tube axis and forms a vortex which creates cold and hot gas fractions situated respectively near the axis and at the periphery. Relatively colder and warmer gas fractions are discharged via the outlet conduit 15 and outlet 16, respectively, in a ratio controlled by the valve 17. The latter fraction is usually called the hot gas, although it may, because of the cooling by the coil 18, have a temperature not far above that of the feed gas. The rotational movement occurs along all or most of the tube 10, decreasing in intensity toward the hot end, and it was found to be desirable to employ long tubes to insure the stability of the vortex at the inlet zone, even though little or no further heat separation occurs in the hot end. The first region, wherein a strong heat separation effect is realized, extends only for a short distance, usually not over about two to five tube diameters measured from the inlet 12. The remaining part of the tube 10 constitutes the second region.

In a relatively long vortex tube, i.e., one longer than twenty tube diameters, there are two zones where cooling by means of a cooling body within the tube is particularly desirable, that between three and five tube diameters from the gas inlet and that between ten and twenty diameters distant from said inlet. These zones correspond approximately to the above-mentioned first and second regions and the distances stated apply when the vortex tube is operated under optimum conditions, viz., at an

expansion ratio of approximately 4 and with the throttle valve 17 set so that 75% of the feed gas is drawn off as the cold gas stream through the conduit 15. It is mainly in the first of these zones that it is important to design the cooling body so as not to disturb the gas-flow patterns and to permit radial flow; spacing of the turns of the helix 18 in the second zone is not so important and can be omitted. However, it is nevertheless desirable to provide flow passages through the helix also in the second zone since in this part also there is some flow of gas from the periphery toward the central axis. In the embodiment shown the single helix 18 extends between points distant 3 and 20 diameters from the gas inlet. Inasmuch as the optimum distances from the gas inlet to the termini of the cooling body depend upon the operating conditions of the vortex tube, it is generally advisable to use the length and location just stated; the position of the latter terminus is not critical and the length of the cooling body may be such that it extends fully to the hot end of the tube.

It is not necessary to draw off gas at the hot end of the vortex tube, and it is possible to shut the valve 17. However, the discharge of some hot gas is generally desirable in that increased discharge of gas at the hot ends lowers the temperature of the cold gas discharged through the cold-gas outlet.

Other forms of cooling bodies and shapes of the vortex tube are possible. For example, as shown in Figures 3 and 4, the tube 10a is cylindrical and the cooling body comprises a cage of helical tubes 22 which communicate with circular headers 23 and 24 coolant being admitted to the former via a pipe 25 and discharged from the latter via a pipe 26. For clarity, only one tube 22 is shown in Figure 3. It is advantageous to make the pitch of the tubes 22 the same as that of the local rotating gas, as previously indicated. The tubes 22 are spaced apart so that passages are provided for the radial flow of gas. As further shown the tubes may have fins 27 to promote heat transfer from the gas. Such fins may also be applied to the tubes of the other embodiments, especially along the parts thereof near the hot end.

In the embodiment of Figure 5 the tube 10b is also cylindrical and the cooling body is in the form of a spiral tube 28 having the overall configuration of a truncated cone. The smaller end of the cone is toward the hot end and a coolant is supplied via a pipe 29 and discharged via a pipe 30.

Example

A vortex tube as shown in Figures 1 and 2 (but without the cooling body) had a tube diameter of 76 mm., a length of 2500 mm., a cold-gas outlet orifice diameter of 45 mm., and eight tangential inlets spaced equally about the inlet zone, each 15.7 x 5 mm. When 1700 kg. of air at a temperature of 5° C. are introduced at a pressure 4.0 atm. abs. and 75% is drawn off as cold gas, the cooling capacity of the vortex tube is 9×10^3 frigories per hour. (A frigory is a unit of refrigeration, equal to a negative calorie.)

When the same tube is externally cooled by a cooling jacket in the known manner, by flowing water at 5° C. through a cooling jacket, and operated as described above, the cooling capacity of the cold gas is 13×10^3 frigories per hour.

If the cooling coil is placed within the tube as shown and water at 5° C. is passed through the helical coil, the same gas flow would produce 16.8×10^3 frigories per hour.

We claim as our invention:

1. In the process for lowering the temperature of a gas by the heat separation effect, wherein a gas stream is expanded with a gyratory motion within the inlet zone of an elongated vortex chamber having a hot end which extends from the inlet zone to form hot and cold gas fractions, cold gas is discharged from the central axis of the chamber and hot gas flows at the periphery of the vortex

chamber from the inlet zone into the hot end with a gyratory motion, the improvement of cooling the gas within the inner part of the hot end at a region displaced from the said inlet zone by passing said gas in heat-exchange contact with a surface situated inwardly from the chamber periphery and cooling the said surface.

2. Improvement according to claim 1 wherein the said cooling is effected at a region of the vortex chamber wherein no substantial heat separation occurs.

3. In the process for lowering the temperature of a gas by the heat separation effect, wherein a gas stream is expanded with a gyratory motion within the inlet zone of an elongated vortex chamber having a hot end which extends from the inlet zone to form hot and cold gas fractions, cold gas is discharged from the end of the chamber opposite to the hot end at a point near the central axis of the chamber, hot gas flows at the periphery of the vortex chamber from the inlet zone into the hot end with a gyratory motion, and return gas flows from the hot end near said central axis into the inlet zone, the improvement of cooling the return gas while in the said end at a region displaced toward the hot end from the inlet zone and inwardly from the periphery of the vortex chamber by passing said gas in heat-exchange contact with a surface situated inwardly from the chamber periphery and cooling the said surface.

4. Improvement according to claim 3 wherein said return gas is cooled by flow in contact with said surface while flowing radially inward from the periphery of the hot end.

5. Improvement according to claim 3 wherein said return gas is cooled by flow in contact with said surface along an axially elongated cooling zone surrounding the central axis of the vortex chamber.

6. Improvement according to claim 5 wherein gas flows from the periphery of the vortex chamber toward the central axis to contribute to the said return gas along the length of said elongated cooling zone.

7. Vortex tube apparatus for lowering the temperature of a gas stream by the heat-separation effect which comprises: an elongated tube defining a vortex chamber; inlet means for admitting said gas stream into an inlet zone of said chamber with a gyratory motion and thereby separating said gas stream into a hot fraction which moves through the tube toward the hot end thereof as a peripheral stream and a cold fraction forming a core within said peripheral stream; cooling means including a cooling wall which is spaced axially from said inlet zone within the hot end of the tube and situated inwardly from the tube wall and further including means for cooling said cooling wall; and a cold-gas outlet for discharging cold gas from said core.

8. Apparatus according to claim 7 wherein said cooling means is a hollow, axially elongated cooling body mounted coaxially within said tube and providing at the central axis a gas-flow passage, said body having confined channels and connecting conduits for flowing a coolant therethrough.

9. Apparatus according to claim 8 wherein said cooling body is displaced from the inlet zone by a distance at least equal to the diameter of the tube at the inlet zone.

10. Apparatus according to claim 8 wherein said hollow body is provided with lateral flow passages for the radially inward flow of gas into said gas-passage.

11. Apparatus according to claim 10 wherein said lateral flow passages are helically shaped.

12. Apparatus according to claim 10 wherein said lateral flow passages are stream-lined to conform approximately to the flow patterns of the gas.

13. Apparatus according to claim 7 wherein said cooling means comprises a spiralized tube having the overall outline of a body of revolution about the axis of the tube and enclosing a central gas-flow passage, and means for circulating a coolant through the tube.

14. Apparatus according to claim 13 wherein the turns

of the spiralized tube are spaced apart axially to provide lateral flow passage for the radial inward flow of gas into said gas-passage.

15. Apparatus according to claim 7 wherein the cooling means is situated in the region of the tube wherein the heat separation does not occur substantially.

16. Apparatus according to claim 7 wherein the internal diameter of said tube diverges toward the hot end in the region containing the cooling means.

17. Vortex apparatus for lowering the temperature of a gas stream by the heat-separation effect which comprises: an elongated tube having an interior surface of revolution about an axis and defining a vortex chamber; one or more inlets disposed tangentially to said surface and dividing the tube into a hot and a cold end situated,

respectively, on opposite sides of the inlet; means providing at said cold end a discharge orifice for said cold gas; means for discharging hot gas from the hot end; a hollow cooling body providing a central gas-flow passage and spaced radially inwardly from the tube wall mounted coaxially within the hot end and displaced from said inlets a distance at least three times the diameter of the tube at the inlets, said body having confined channels; and means for circulating a coolant through said channels.

References Cited in the file of this patent

UNITED STATES PATENTS

2,730,874 Schelp Jan. 17, 1956