

[54] **EXPANSION TURBINE SEPARATOR**
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Attorney—Karl F. Ross

[30] **Foreign Application Priority Data**
July 15, 1970 Germany..... P 20 35 138.6

[52] **U.S. Cl.**..... 55/405, 55/406, 415/121, 415/168, 415/205
[51] **Int. Cl.**..... **B01d 45/14**
[58] **Field of Search**..... 415/205, 121 A, 168; 55/400-409

[57] **ABSTRACT**

An expansion turbine, especially for the work expansion of low-temperature liquefiable gases, which comprises around the axis of the rotor a liquid-collecting chamber, communicating with the gas-outflow chamber, provided with an outlet through which the liquefied gas can be led after it is centrifugally collected along the annular walls of this chamber.

[56] **References Cited**
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6 Claims, 4 Drawing Figures

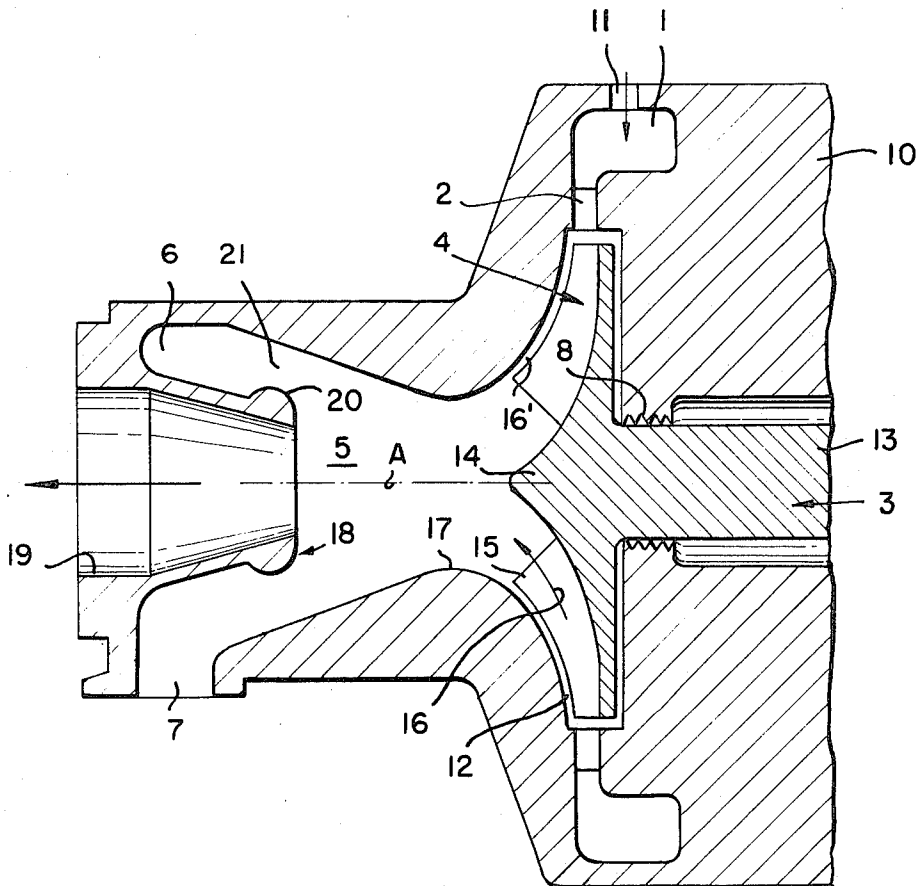


FIG. 1

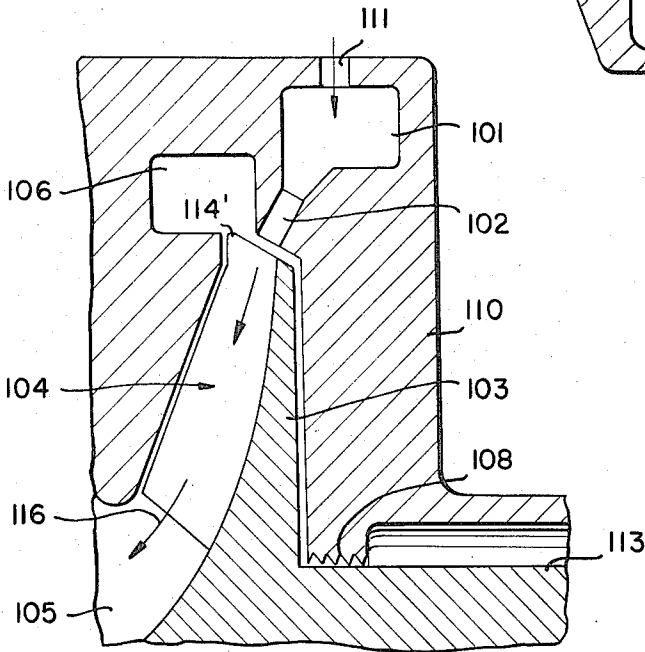
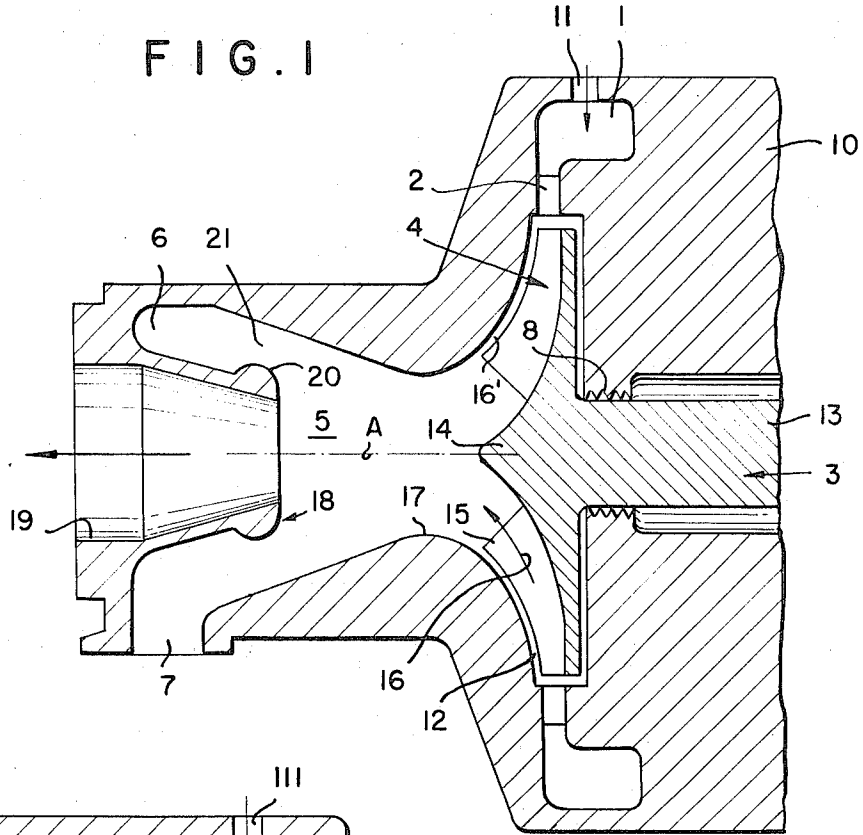


FIG. 2

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FIG. 3

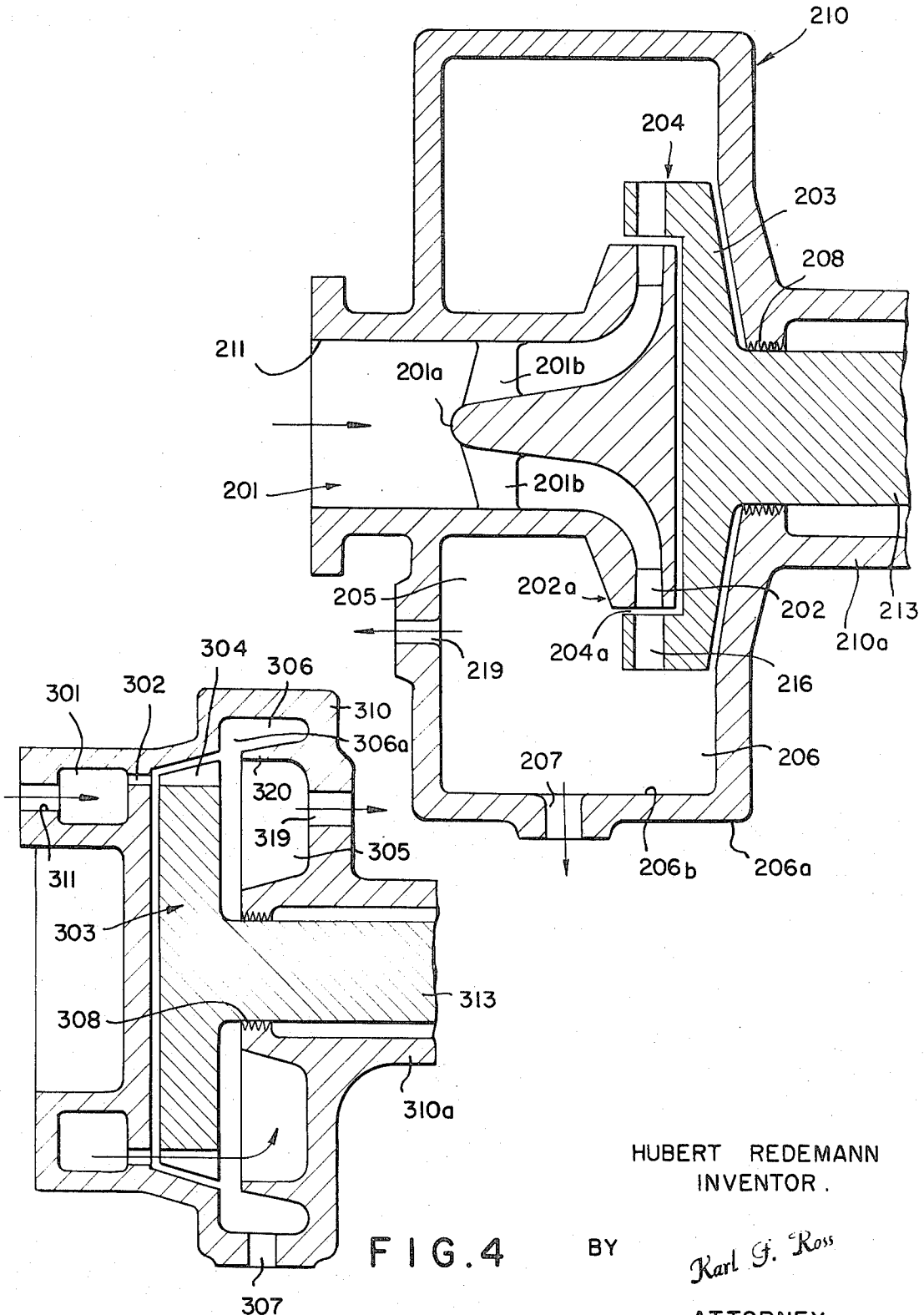


FIG. 4

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EXPANSION TURBINE SEPARATOR

FIELD OF THE INVENTION

My present invention relates to an expansion turbine and, more particularly, to an expansion turbine for the work expansion of low-temperature liquefiable gases.

BACKGROUND OF THE INVENTION

In low-temperature technology, e.g. in installations for the liquefaction of gases, it is frequently necessary to expand a compressed gas or liquid/gas mixture to reduce the temperature thereof by creation of mechanical work. Such expansion may be carried out in so-called expansion turbine in which the expandable fluid is introduced via a nozzle array into the main gas-outflow chamber of the turbine and is directed against a rotor, provided with vanes, blades or the like, which is rotated with predetermined loading which may range from the rotational friction of the rotor to that of some driven member or load connected thereto. At the discharge side of the turbine, the expanded fluid, generally a gas, is collected for further use in the cryogenic installation or for discharge, depending upon the requirements of the cryogenic process.

The principles of such expansion turbines and earlier turbine structures are described in the commonly assigned U.S. Pats. No. 3,552,878 and No. 3,398,929.

In all of the expansion-turbine systems described generally above, the expansion turbine has been so constructed that the gas entering the turbine is generally in a state above the $x = 1$ level of the temperature/entropy (T, s) diagram of the system, where x is a measure of the liquid-component content of the gas, where s is the entropy and T is the absolute temperature. During the expansion of the turbine, the ratio x increases so that some gas is transformed into liquid. In conventional systems, it has been desired to maintain the liquefaction level as low as possible because the liquid droplets formed in the expansion turbine may damage the high-speed rotor fans or blades, etc. Hence, expansion turbines have not been used generally for producing large volumes of liquefied gas and, in many cases, extreme measures have been used to reduce the liquid content of expansion-turbine gases. I may also note that, for practical reasons, it is highly desirable to be able to use an expansion turbine for the liquefaction of gases.

OBJECTS OF THE INVENTION

It is the principal object of the present invention to provide an expansion turbine which is able to avoid the aforementioned disadvantages and to enable the expansion turbine to be used for the recovery of liquefied gases with a minimum of difficulty.

It is another object of the invention to provide an improved expansion turbine facilitating the recovery of liquid produced by liquefaction of a gas.

SUMMARY OF THE INVENTION

These objects and others which will become apparent hereinafter are attained, in accordance with the present invention, in a system which comprises a vaned or bladed (channeled) rotor, housing means defining a nozzle arrangement at one end of this rotor for training the expanding fluid thereagainst, thereby driving the rotor and permitting some liquefaction of the gas, and means forming a gas-recovery or gas-collection chamber around the rotor for leading the expanded gas away

from the latter; the invention provides a liquid-collection chamber or compartment of annular configuration adjacent (and in communication with) the gas-collection chamber and having at least one annular wall in the path of liquid cast centrifugally outwardly by the rotor, for collecting this liquid and returning it from the housing. The advantage of this system is that it enables the separation of the gas phase from the liquid phase in an especially simple manner.

The liquefied may also be described by stating that the gas-discharge or gas-outflow chamber of the expansion turbine is provided with, or is connected to, a collecting compartment for the gas liquefied by expansion, located outwardly of the main gas flow from the end of the rotor in the path of the liquefied gas (liquid) centrifugally cast from the latter.

The rotor thus acts both as a work-expansion member and as a centrifugal separator of the high-density phase (liquid) from the low-density phase (expanded gas). Centrifugal force provides the means for separation and, because the liquid droplets have higher mass or density than the gas particles, the liquid droplets are forced outwardly more readily than the gas particles. The droplets collect along the annular wall mentioned earlier and displace the gas which is then confined to the main stream as described.

It will be apparent that the efficiency of the system described above is dependent upon a number of factors, one of which is the duration of contact between the expanding gas phase and the liquid phase on the rotor, i.e. the residence time, since the greater the residence time, the larger are the liquid particles. Other factors include the rotor speed, loading, etc. The first factor, however, can be increased, according to the present invention, by extending the rotor and providing the vanes, blades, channels and passages thereof of some length, preferably the channels have lengths greater than the radial distance between the inlet and outlet portions of the rotor and extended by causing the channels to run along spirals, etc. Furthermore, the rotor need not be a planar disk but may have an axially extending portion formed with the channels to increase the duration of contact. The increased lengths of the channels, of course, increases the duration over which the particles are to be found in the centrifugal force field.

To avoid cavitation, which is detrimental to the rotor, the channels, vanes, blades or scoops are so constructed (with increasing flow cross-section in the flow direction) and arranged that the liquid phase is continuously accelerated for the entire duration of its contact with the rotor. Radial channels and generally spiral channels may be used for this purpose. Surprisingly, the rotary entrainment of the liquid phase necessary for the continuous acceleration, results in the imparting to the liquid phase cast from the rotor of an angular component or a rotational component which is maintained in the space beyond the rotor and further centrifugally causes the liquid to be brought outwardly into contact with the collecting wall. In other words, the residual angular displacement of the fluid discharge from the rotor increases the efficiency with which the phases are separated.

The expansion turbine of the present invention may be so operated that the gas is introduced in a state between liquid and gas phase and which in the temperature/entropy diagram lies above the limiting curve

$x = 0$. During expansion, the gas state changes so that the limiting curve $x = 0$ is crossed and the gas is adiabatically expanded. A large quantity of heat is thus removed and an exceptionally large proportion of the gas is converted to liquid. In practice, the liquefaction proportion exceeds that which can be obtained practically by expansion of the gas through a throttle.

According to another feature of this invention, the liquid-collecting chamber is provided as an annular space coaxially surrounding the axis of rotation of the rotor and is provided with a single discharge port for the liquefied gas. For the improved separation of the liquid phase from the gas phase, it is also desirable to separate or partition the gas-discharge chamber from the liquid-collection chamber. The use of partitions of this type has been found to be particularly desirable with axial-expansion turbine installations. With radial-expansion turbines, it has been found to be possible to locate the liquid collection chamber in close proximity to the periphery of the rotor and even to the nozzle chamber at which the gas is introduced.

DESCRIPTION OF THE DRAWING

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is an axial cross-sectional view through a portion of a radial-expansion turbine according to the present invention (wherein the gas expands in the radial direction);

FIG. 2 is a detail in axial cross-section of a modification of the system of FIG. 1 with a different arrangement of the liquid-collecting chamber;

FIG. 3 is an axial cross-sectional view of a radial-expansion turbine according to another feature of the invention; and

FIG. 4 is an axial cross-sectional view of an axial-expansion turbine embodying the present invention.

SPECIFIC DESCRIPTION

In FIG. 1 of the drawing, I have shown an expansion turbine which comprises a housing 10 which has been shown in one piece but may be assembled in accordance with acceptable machine design practice, from any number of parts. The housing 10 is formed with an annular chamber 1 coaxial with the rotor axis A and receiving a compressed or pressurized gas through an inlet 11. The chamber 1 is provided along its inner periphery with a nozzle compartment 2, is divided into nozzles of the type described in the aforementioned patents. In addition, the housing 10 is provided with a turbine compartment 12 in which a rotor 3 is received. The rotor 3, comprising a shaft 13 and a blade disk 4, is journaled in the housing 10 by conventional means, e.g. gas bearings, and is surrounded by labyrinth seal 8 to prevent leakage of gas from the chamber 5. As is also apparent from FIG. 1, the disk 4 comprises a central boss 14 surrounded by a crown of vanes, blades or scoops 15 defining radially widening flow channels represented by the arrow 16. The blades may be of spiral configuration to maintain a continuous acceleration of the gases as they pass inwardly. The disk 4 is, moreover, of bicuspid configuration and is symmetrical about the axis A.

Forwardly of the disk 4, the housing 10 is provided with an inwardly converging wall 16, closely following

the profile of the rotor and rotationally symmetrical about the axis A. Furthermore, the chamber 5 is of Laval-nozzle configuration and widens its narrowest point 17 axially away from the rotor. At the discharge end of the chamber 5, the housing is provided with an inwardly extending axial boss 18 defining the gas outlet 19. The boss 18 also constitutes an axially outwardly divergent frustoconical partition defining an annular chamber 6 ahead of the main chamber 5. The chamber 6, of course, serves as a liquid collection space and is formed with a radial outlet 7 for the liquefied gases. The partition 18 is formed with an annular ridge 20 defining a slight constriction 21 between chambers 5 and 6.

When liquefiable gas is introduced at high pressure into compartment 1, it traverses the tangentially oriented nozzles 2 which direct the gas inwardly against the outer peripheries of the rotor disk 4 to drive the latter at high speed in accordance with the principles of expansion-turbine operation. As the gas passes inwardly along the flow channel 16 of the rotor, it expands, cools and partially liquefies, further expansion being effected in the chamber 5 which widens ahead of the constrictional 17. As the liquids and gases pass along the rotor, the liquid is continuously accelerated and, because of the centrifugal force and the general axial movement of the fluid, moves in a helical or spiral path in the direction of the outlet 19. Since the centrifugal force is most effective for the liquid droplets as already noted, the liquid forms an outer layer along the walls of the chamber 5 and eventually is intercepted by the chamber 6 which, as shown, has the form of a pocket open generally inwardly and axially in the direction of the rotor. The liquid is delivered by gravity to the outlet 7 and is removed from the system. The chamber 6 is, of course, rotationally symmetrical about the axis 1 and lies outwardly of the outlet 19.

In FIG. 2, there is shown another embodiment of the invention wherein the housing 110 is provided with the labyrinth seal 108 as previously described and rotatably receiving the shaft 113 of the rotor 104. In this modification of the system of FIG. 1, however, the expansion nozzles 102 are shown to be directed inwardly and forwardly from the pressurized gas chamber 101 which receives the gas at 111. A pocket or liquid-collecting chamber 106 is provided along the external peripheries of the rotor 103 which has channels 116 defined by the rotor blades as previously described. A radial outlet (not shown) is provided for the chamber 106 which collects centrifugally outwardly cast liquid. The tops 104' of the blades and the ends of the channels of the rotor 103 may terminate in the chamber 106 to ensure interception of the centrifugally shedded liquid. In addition, a pocket 6 may be provided axially downstream of the rotor as described in connection with FIG. 1 and the chamber 105 may have the Laval-nozzle shape mentioned earlier. At the base of the annular pockets 106 and 6 of the system, there may be provided radial outlets as shown at 7 of FIG. 1 for discharge of the liquid phase.

In FIG. 3 I have shown an expansion turbine of the radial type wherein the housing 210 is formed with an annular portion 206a defining a chamber 206 surrounding the rotor 203. The latter is here constituted with a shaft 213 journaled in a sleeve portion 210a of the housing which is provided with a labyrinth seal 208 in the manner previously described. The disk portion

204 of the rotor is formed with an axially open cavity 204a fitting over a disk portion 202a of the nozzle assembly. Outwardly of the cavity, the rotor is provided with radial passages 216 having a function similar to that of the channels of the rotors of the previous embodiments.

The chamber 206, for collection of the liquid phase, immediately surrounds the rotor disk 204 and provides a wall 206b radially outwardly thereof and against which the liquid phase is centrifugally cast. A drain 207 is provided, as previously described, for discharge of the liquid phase. In this embodiment, the pocket 206 is provided in a single continuous chamber with the compartments 205 through which the gas phase is permitted to pass via an outlet 219.

The stator portion of the assembly comprises the nozzle disk 205a, as previously described, the latter being formed on the inner end of a sleeve 201 simultaneously providing a duct 211 for ingress of the compressed gas phase. Within the sleeve 201, there is provided a deflecting body 201a held in place by struts 201b which communicates with the nozzles 202. The nozzles 202 are here trained tangentially against the rotor 203, 204 and direct their respective jets against the latter from the inside. As the compressed gas emerges from the outlet at high velocity because of expansion, it drives the rotor and expands further with cooling to produce the liquid phase. Otherwise the system operates in the manner previously described in that the liquid phase is collected in the annular chamber 6. The blades defining the channels 216 are so constructed and arranged that the liquefied gas is centrifugally cast on the outer wall of chamber 6 and can be recovered at 7 at the bottom of the apparatus. The gas phase is, of course, removed parallel to the axis of rotation at outlet 5.

In FIG. 4, I have shown still another system embodying the invention. The axial expansion turbine of FIG. 4 comprises a housing 310 in which the rotor 303 is journaled. In this embodiment, the rotor 303 comprises a shaft 313 journaled in a sleeve portion 310a of the housing and co-operating with the seal 308 whose function has been described previously. The housing 310 is formed ahead of the rotor 303, with an annular gas-distributing chamber 301 which surrounds the rotor axis and is provided with an inlet 311 for the compressed gas. The chamber 301 constitutes a manifold communicating with a multiplicity of nozzles 302 trained generally axially against the helically inclined veins 304 of the disk portion of the rotor, the veins being provided at the periphery thereof. Furthermore, the veins are so constructed and arranged as to permit continuous acceleration of the gases as they traverse the rotor. Radially outwardly of the veins 304, I provide a pocket 306 of annular configuration, coaxial with the rotor and the distribution chamber 301 such that, on the discharge side of the rotor and outwardly thereof, an opening 306a is formed to permit entry of the liquid phase. The gas-collecting chamber 305 lies radially inwardly of the annular chamber 306 and is separated therefrom by a wall 320. While the liquid-collecting pocket 306 is provided with a radial outlet 307 on the bottom of the apparatus, the gas compartment 305 is formed with the outlet 319 at the upper side of the unit. Here again, the system operates in the manner described in connection with FIGS. 1 and 2.

It will be apparent that all of the described embodiments, with the exception of the compartment 106 of

FIG. 2, the liquid-collecting pocket is disposed ahead of the discharge side of the rotor and outwardly thereof to collect the axially and centrifugally outwardly moving liquid component. Furthermore, in all cases, the liquid-collecting pocket is disposed outwardly of the expanded gas chamber and, with the exception of compartment 106, surrounds this gas chamber.

The improvement described and illustrated is believed to admit of many modifications with the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the invention except as limited by the appended claims.

I claim:

1. An expansion turbine for the substantially adiabatic expansion of a liquefied gas to at least partially liquefy same, comprising a housing formed with a compressed-gas chamber having an inlet and an expanding-gas chamber; a radial-passage turbine rotor journaled for rotation in said housing extending into the expanding-gas chamber and having a peripheral portion; nozzle means communicating with said compressed-gas chamber positioned about the peripheral portion of the rotor for training jets of liquefied gas upon the periphery of said rotor at one end of said expanding-gas chamber; and means forming an annular liquid-collecting compartment inwardly axially offset from said compressed-gas chamber and collecting liquid cast outwardly by said rotor and separating said liquid from gas within said expanding-gas chamber, a central tubular portion of said housing extending axially into said expanding-gas chamber from said other end and forming therewithin an axial outlet of a diameter less than that of said expanding-gas chamber and defining with said rotor a principal gas-flow direction from said inlet axially to said outlet with a flow cross-section increasing in said direction, said liquid-collecting compartment being formed around said tubular portion including a liquid outlet.

2. The expansion turbine defined in claim 1 wherein said liquid-collecting compartment is and coaxial with said rotor.

3. The expansion turbine defined in claim 2 wherein said turbine rotor is of the radial-expansion type and another annular liquid-collecting compartment is disposed between said nozzle means and the periphery of said rotor.

4. The expansion turbine defined in claim 2 wherein said rotor is formed with channels traversed by the expanding fluid and maintaining acceleration thereof against said rotor.

5. The expansion turbine defined in claim 2 wherein said rotor is of the radial-expansion type and is provided with a disk portion forming inwardly widening channels opening along said periphery of said rotor, said nozzle means including an array of nozzles surrounding said periphery and trained inwardly thereagainst, said expanded-gas chamber being of Laval-nozzle shape axially ahead of said rotor and widening in the direction of said outlet, said outlet being defined centrally in said expanded-gas chamber by said wall and said compartment being formed outwardly of said wall and being provided with a radial port for discharge of the liquid collected thereby.

6. The expansion turbine defined in claim 2 wherein said compartment is formed with a wall outwardly of said rotor and in the path of the centrifugally discharged liquid while being provided with a port at a lowermost portion of said wall for draining liquid from said compartment.

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