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Takashima et al.

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[54] **CENTRIFUGAL GAS SEPARATOR**

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[52] **U.S. Cl.** **55/407,** 55/17, 233/13, 233/47

[51] **Int. Cl.** **B01d 45/12**

[58] **Field of Search** ..... 55/17, 400, 407; 233/1 R, 11, 13, 27, 28, 46, 47 R

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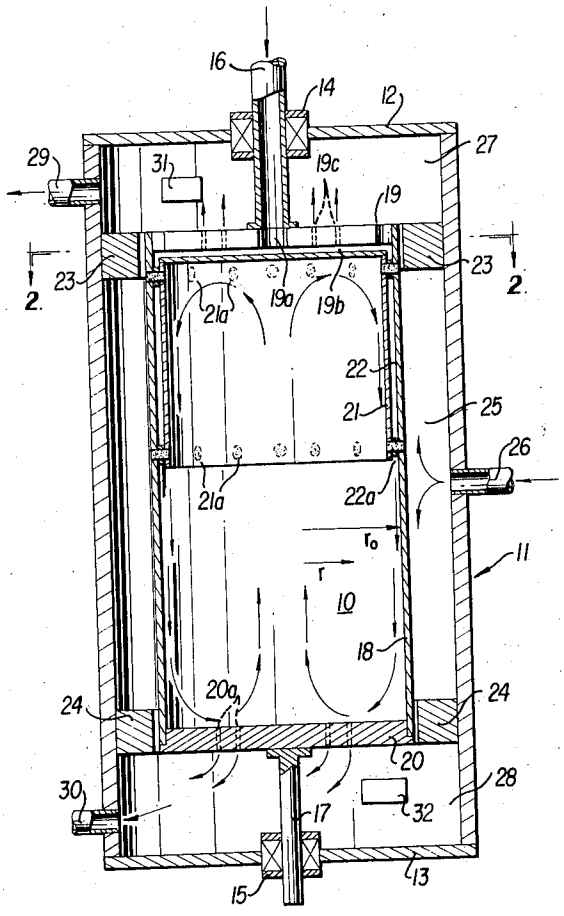
[57] **ABSTRACT**

A centrifugal gas separator is disclosed which employs a cylindrical centrifuge drum having a hollow shaft mounted on suitable bearings within a housing. Supply means are provided for feeding a mixed gas to be separated into the drum. The supply means has openings located radially near the inner periphery of the drum and axially at approximately the center of the drum. Each opening in the supply means communicates with the hollow shaft. Thus the mixed gas to be separated enters the centrifuge drum near the inner periphery thereof, and the gas is then able to attain a relatively high angular velocity, whereby the separating power of the centrifuge is elevated.

8 Claims, 5 Drawing Figures



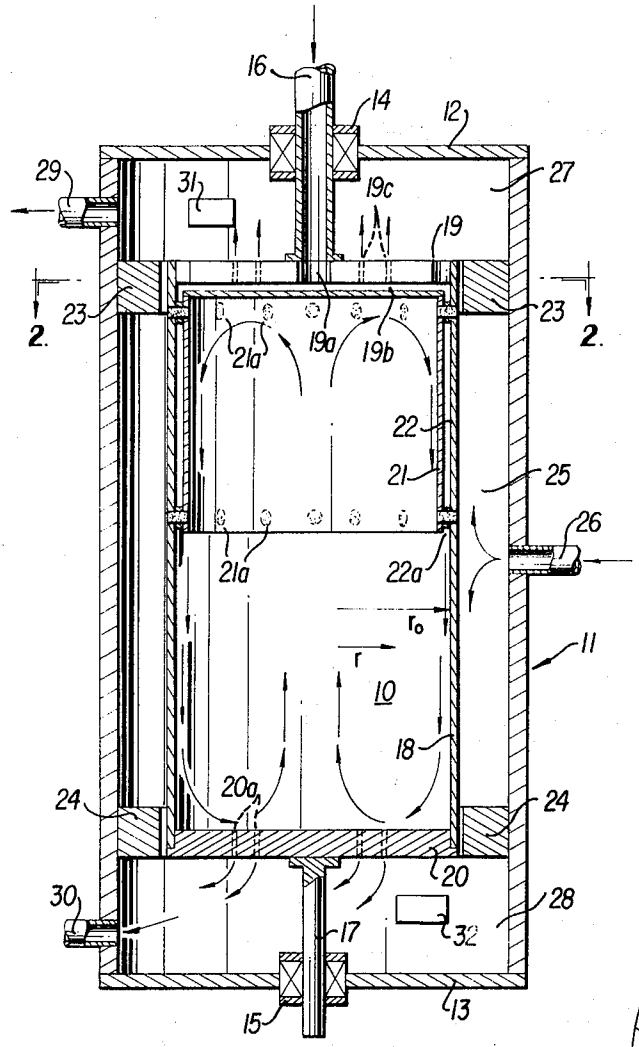


FIG. 1

FIG. 2

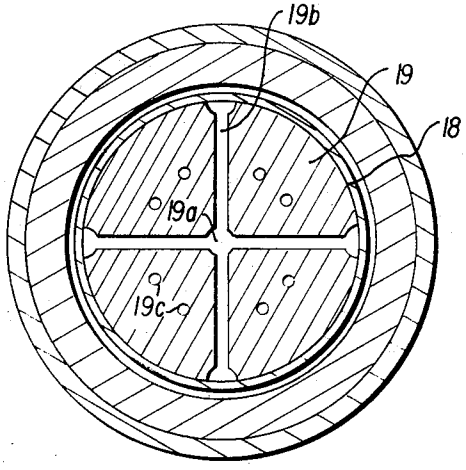
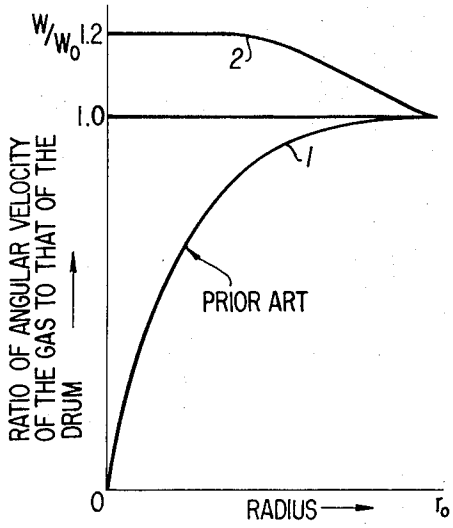


FIG. 3



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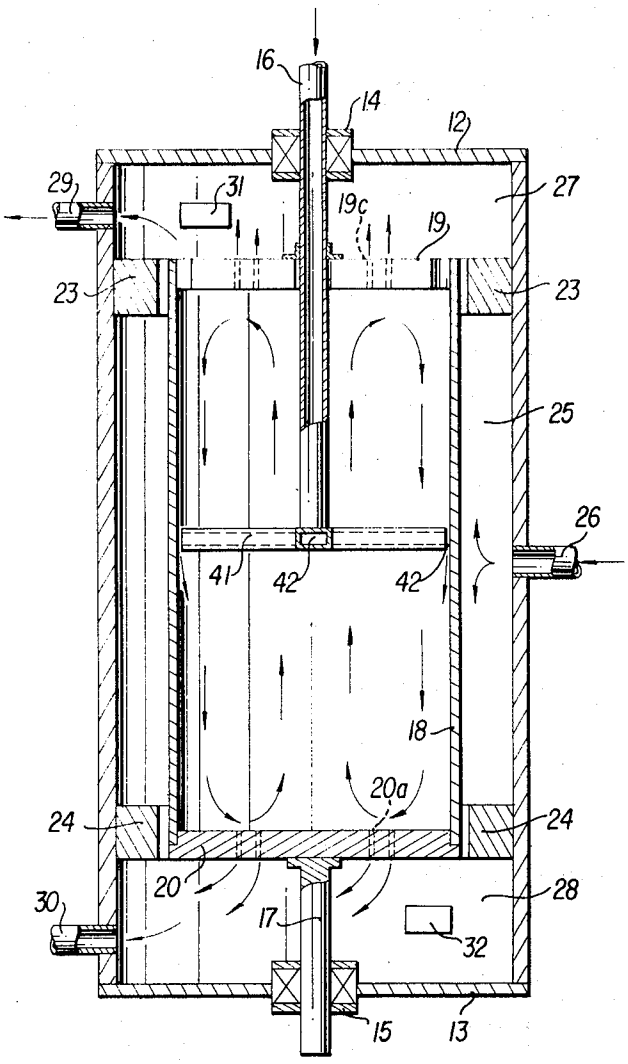
16
14
12
29
31
19c
19
27
23
23
25
26
41
42
42
18
20a
24
24
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28
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32
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13

FIG. 4

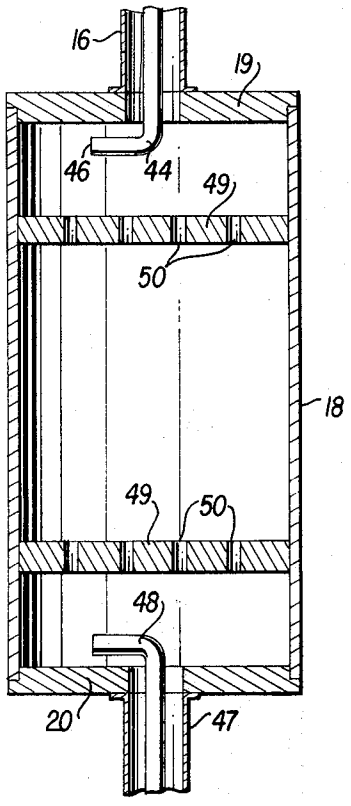
16
19
46
44
49
50
18
49
50
48
20
47

FIG. 5

CENTRIFUGAL GAS SEPARATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to gas separators and more particularly to centrifugal gas separators for an isotopic separation.

2. Description of the Prior Art

Gas centrifuges of the type having a countercurrent with circulation customarily included an elongated cylindrical drum vertically oriented and having a hollow centrally located shaft. A mixed gas to be processed is supplied to the drum at the central portion thereof through the hollow shaft to fill the drum. The mixed gas in the drum is rotated at an extremely high angular speed, thereby subjecting it to a large centrifugal force. Hence, by pressure diffusion, the gas near the inner periphery of the drum becomes enriched with heavier molecules and the gas near the central portion of the drum becomes enriched with lighter molecules. In order to obtain a countercurrent, several alternative methods may be used. For example, a heater and a cooler may be provided for causing a thermal convection, thus establishing a countercurrent. One end of the centrifuge drum may be kept at a slightly elevated temperature, and the other end at a somewhat lower temperature than that of the gas. At the warm end, the gas flows radially inward, while the gas flows radially outward at the cool end. In the inward flow, as the gas is directed to the center of the drum, the gas should be reduced in volume. However, since a reduction in the volume of the gas is impossible near the center portion of the drum, the excess volume of gas has to flow off in an axial direction. The volume of the gas will tend to increase as the gas moves outwardly, whereby the gas is withdrawn axially through the central portion of the drum. In the relatively smaller radius portion of the drum, the gas flows from the warm side to the cold side. Along the cylinder wall, the gas flows from the cold side to the warm side in a thin stream. Thus the gas of lighter molecular weight collects near the cold end while the heavier gas collects near the warm end.

It is well known that the maximum separating power of the gas centrifuge is proportional to the length l of the drum in the axial direction and to the fourth power of the peripheral velocity $(r_o\omega_o)^4$ of the gas, where r_o denotes the inner radius of the drum and ω_o denotes the angular velocity of the drum.

In reality, however, the separating power obtained is substantially smaller than the above described theoretical value for various reasons, such as failure to obtain a suitable countercurrent and flow pattern, for example. In addition, as there exists an outward gas flow in a radial direction due to the influx of mixed gas to be processed through the hollow shaft at the center of the drum, the greater part of the gas has a smaller angular velocity than that of the drum.

In case there is no supply or exhaust of the gas into and from the drum, the viscosity of the gas causes the portion of the gas in contact with the cylindrical drum wall to have a velocity substantially equal to that of the drum wall. This part of gas imparts the same circular motion to an inner ring-like portion of the gas due to the viscosity thereof. Accordingly, the gas in the drum comes to have an angular velocity equal to that of the drum in the steady state. But, where there is a supply of gas at the central portion of the drum and a radially outward flow, most of the gas in the drum has a smaller angular velocity than that of the drum. This phenomena may be understood by a calculation taking the viscosity of the gas into consideration.

SUMMARY OF THE INVENTION

Therefore, one object of this invention is to provide a centrifugal gas separator capable of rotating a mixed gas in a drum thereof at a velocity greater than that of the drum.

Another object of the present invention is to provide a centrifugal gas separator wherein a mixed gas to be separated is supplied to a centrifuge drum at one or more portions near the inner periphery of the cylindrical drum wall.

Briefly stated, a centrifugal gas separator in accordance with the invention employs a drum which is rotatably supported within an enclosed housing and driven by a suitable means, and exhaust means for removing separated gases. There is provided means for supplying the mixed gas to be separated into the drum at one or more portions a distance from the axis of rotation of the drum.

BRIEF DESCRIPTION OF THE DRAWINGS

The instant invention will be better understood and its various objects and advantages will be more fully appreciated from the following description taken in conjunction with the accompanying drawings in which:

FIG. **1** is a sectional view of a first embodiment of the present invention;

FIG. **2** shows a cross sectional view of an upper portion of the drum of the first embodiment shown in FIG. **1** taken along a line **2—2** of FIG. **1**;

FIG. **3** is a plot of the angular velocity of a gas in a centrifuge drum with respect to radial distance where the ordinate is labeled with ratio of angular velocity of the gas to that of the centrifuge drum, and the abscissa is labeled with distance in the radial direction from an axis of the drum;

FIG. **4** shows a sectional view of a second embodiment of the instant invention; and,

FIG. **5** is a sectional view illustrating an alternative gas exhaust structure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, and more particularly to FIG. **1** thereof, a centrifuge drum **10** is shown located in a housing **11.**

The housing **11** is a type of a vacuum tank and has a top cover **12** and a bottom cover **13.** On the top and bottom covers **12** and **13,** there are provided supporting devices **14** and **15** for rotatably supporting a hollow shaft **16** and a shaft **17** of the drum with a damping and sealing action. The supporting device may include a bearing, the outer race thereof being carried by a resilient member such as a rubber damper which is mounted on the housing **11,** and a sealing member such as a face seal arrangement.

The drum **10** comprises a cylindrical wall **18,** a top disc member or lid **19** having the hollow shaft **16** secured thereto for supplying a mixed gas to be processed into the drum **10,** and a bottom disc member or lid **20** having the shaft **17** secured thereto. The top disc **19** is

provided with a center hole **19***a* and a plurality of conduits **19***b* (shown in FIG. **2**) extending radially outwardly from the hole **19***a*. Thus, the hole **19***a* communicates with the hollow portion of shaft **16** and with the radial conduits **19***b*. The top lid **19** may either be made of a single plate or may be formed of two parts, i.e., an upper and a lower disc. In latter case, the lower disc may be made as an integral part of an inner cylindrical member or cylinder **21.** The inner cylinder **21** has an axial length about one half of that of the drum, and is mounted beneath the upper disc **19** so as to provide a ring-like clearance **22** between its outer wall and the wall **18** of the drum **10.** At the top and bottom outer peripheral portions of the inner cylinder **21,** there may be provided a plurality of projections **21***a* with a suitable spacing therebetween for fixedly securing the inner cylinder **21** to the wall **18** of the drum **10.** The ring-like gap **22** communicates with the outer end portions of the conduits **19***b* of the disc member **19.** Accordingly, a supply of the mixed gas is provided through the conduit which is formed of the hollow shaft **16,** hole **19***a*, the radial conduits **19***b* and the gap **22,** which opens at the lower end into the inner cylinder **21.** When the mixed gas passes through the radial conduits and the gap successively, it is given rotational motion. The mixed gas comes to a circulating speed substantially equal to that of the drum wall **18** and is fed into the drum through a ring-like opening **22***a* between the lower edge of the inner cylinder **21** and the drum wall **18.**

Through the upper lid **19,** there are provided a plurality of small holes or openings **19***c* oriented parallel to hollow shaft **16,** and disposed in a circle of about one half the radius of the drum, with a suitable spacing with respect to each other so as not to communicate with the radial conduits **19***b* of the disc **19.** These holes **19***c* serve to exhaust the lighter portion of the separated gas. Through the lower disc member **20,** there are also provided a plurality of small openings **20***a* similar to the openings **19***c* of the upper disc **19,** which serve to exhaust the heavier portion of the separated gas.

There are provided ring-like baffle members **23** and **24** mounted on the housing **11** to form a relatively small gap therebetween. A chamber **25** defined by the drum **10,** the baffles **23** and **24,** and housing **11,** is filled with a gas such, for example, as helium supplied through an inlet **26** for preventing each of the separated gases in the upper chamber **27** and lower chamber **28** from flowing into the common area **25** to recombine. The separated gases in the upper and lower chambers **27** and **28** are exhausted together with a small quantity of the helium gas flowing from the common area **25** through a pair of outlets **29** and **30** to the next processes (not shown).

There are further provided a cooler **31** and a heater **32** for cooling and heating the upper and lower discs **19** and **20,** respectively, so that a thermal convection may be obtained to establish a countercurrent. The upper lid **19** may be cooler than the lower lid **20** by 10 to 20° C.

In operation, the centrifuge drum **10** is driven by a suitable drive such as an electric motor to rotate it at an extremely high speed. Then the mixed gas is put into the drum and subjected to centrifugal force so that the gas of lighter molecular weight tends to move radially inward and the gas of heavier molecular weight tends to move radially outward by pressure diffusion.

At the same time, along the upper lid **19** which is relatively cooler than the gas, the gas flows radially outward by thermal convection. On the other hand, along the lower lid **20,** which is warmer than the gas, the gas flows radially inward by thermal convection. Then the portion of gas positioned away from the drum wall **18** flows upward, and the gas near the drum wall flows downward along the drum wall in a relatively thin stream.

Accordingly, as a whole, the lighter gas gathers near the top lid **19** and is exhausted through the openings **19***c* to fill an upper chamber **27.** The small amount of the gas, which flows through the gap between the drum **18** and the baffle **23** from the chamber **25,** and the lighter gas in the upper chamber **27** are taken out through the outlet **29,** and then separated from each other by a suitable separator such, for example, as a cold trap device (not shown). Similarly, the heavier gas gathers near the bottom lid **20** and is exhausted through the openings **20***a* to fill the lower chamber **28.** The heavier gas mixed with a small amount of the gas from the common chamber **25** is taken out through the outlet **30** and then further separated.

In accordance with the invention, the mixed gas to be separated is supplied from the ring-like opening **22***a* defined by the inner cylinder **21** and the drum wall **18,** and the separated gases are withdrawn from the openings **19***c* and **20***a* provided on the upper and lower lids **19** and **20** respectively. In other words, the gas is supplied at larger radius positions of the drum and exhausted at smaller radius positions. Hence, there occurs an inward flow in the radial direction as a whole. Furthermore, the supplied mixed gas from the opening **22***a* has a peripheral velocity substantially equal to that of the drum wall **18.**

As there exists a radially inward flow of the mixed gas having a peripheral velocity substantially equal to $r_0\omega_0$, the angular velocity ω of the gas in the drum **18** comes to have a larger angular velocity than ω_0, where r_0 denotes the inner radius of the drum wall **18,** and ω denotes the angular velocity of the gas portion at radius r. This is shown in FIG. **3** in a quantative manner, wherein the ordinate represents ω/ω_0, the abscissa represents r, and the curves **1** and **2** respectively represent the prior art and the instant invention. This phenomena may be understood through calculations taking the viscosity of the gas into consideration.

Thus, according to the instant invention, the major portion of the gas in the drum has a larger velocity than that of the centrifuge drum, and the separating power of the system is consequently substantially increased because it is proportional to the fourth power of the angular velocity of the gas, as hereinbefore set forth.

Since the gas in the upper portion of the drum is enriched with the lighter gas and the gas in the lower portion with the heavier gas, there exists a concentration gradient along the axial direction of the drum with respect to the heavier and lighter gases. The supply of the mixed gas to be separated is preferably made at the portion in the drum having a mixture of lighter and heavier gases substantially equal to that of the mixed gas to be supplied. Accordingly, the length of the inner cylinder **21** in the axial direction is selected to be about a half of the inner axial length of the drum **18.**

The radially inward flow is obtained by the displacement, in the radial direction, of the position where the gas is exhausted from the position where the gas is sup-

plied. The openings provided on the upper and lower lids for exhausting the separated gases are preferably positioned at as small a radius as possible. However, the nearer they are positioned to the center, the smaller is the gas pressure, so that it is more difficult to exhaust the separated gases. Hence, the openings for exhausting the separated gases are arranged on circle of about one half the radius of the lids in this embodiment of the instant invention.

Referring now to FIG. 4 which shows another embodiment of the instant invention, the hollow shaft **16** is shown extending axially down through the upper lid **19** into the central portion of the drum **18.** Secured to the lower end of the hollow shaft **16** is a pipe member **41** extending radially in four directions so as to form four radial passages, each communicating with the hollow shaft **16** at one end and having an outlet **42** at the other end, opening near the inner periphery of the drum **18.** The top lid **19** does not include the radial conduits **19***b* as shown in FIG. **1,** but does include the central opening for the shaft **16** and the exhausting openings **19***c*.

The operation of this embodiment is substantially identical to that of FIG. **1,** and will be understood from the description above.

In these embodiments, there are provided a plurality of openings on the upper and lower lids of the drum for taking out the separated gases. However, other devices can be used for this purpose.

One example of such a device, illustrated in FIG. **5,** employs a stationary pipe **44,** which passes through the hollow shaft **16** with a clearance therebetween, having a rectangular bend therein as it enters the drum **18** near the lid **19,** and having an inlet opening **46** at one half the radius of the drum **18.** In this case the shaft **17** is replaced with a hollow shaft **47** as the lower drum support shaft. A pipe **48,** substantially identical to the pipe **44** is positioned inside the hollow shaft **47.** Further, to prevent disturbance caused by the stationary pipes in the drum, a pair of baffle members of disc shape **49** having small penetrating holes **50** may be disposed near the stationary exhausting pipes **44** and **48** so as to form a chamber for the stationary pipes. In this embodiment, the gas in the chamber **25** and the baffle members **23** and **24** for preventing recombination of the separated gases are not necessary, but the construction of the centrifuge is rather complicated so that difficulties in maintenance and inspection, and the like, may arise.

According to this invention, as it is possible to obtain radially inward flow in a centrifuge drum, and the gas in the drum is able to attain larger angular velocity than that of the drum, thereby to achieve an increased separating power.

Obviously, numerous additional modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described herein.

What is claimed as new and desired to be secured by letters patent of the united states is:

1. A centrifugal gas separator comprising:
drum means driven at a high rotational speed and adapted to receive a mixed gas to be separated;
a housing for enclosing said drum means;
means for rotatably supporting said drum within said one of said disc members which is secured to said hollow shaft; and,
an inner cylindrical member mounted inside said cylindrical wall of said drum to form a passage between said cylindrical member and said cylindrical wall, said passage communicating with said conduit.

2. A centrifugal gas separator according to claim **1,** wherein:
said supply means has at least one opening communicating with said hollow shaft, said opening being axially disposed at an intermediate portion of said drum near the inner periphery of said cylindrical wall.

3. A centrifugal gas separator according to claim **1,** wherein said supply means comprises:
an axial passage extending from said hollow shaft along an axis of said drum and communicating therewith; and,
at least one passage extending radially from a free end of said axial passage and communicating therewith and having an opening near the inner periphery of said cylindrical wall of said drum.

4. A centrifugal gas separator according to claim **3,** wherein:
the length of said axial passage is approximately one half that of said drum.

5. A centrifugal gas separator according to claim **1,** wherein said exhaust means comprises:
a plurality of perforations in each said disc member at an intermediate portion thereof; and,
separating means for preventing a gas exhausted from said perforations in one of said disc members from mixing with another gas exhausted from said perforations in said other of said disc members.

6. A centrifugal gas separator comprising:
an enclosed housing;
a drum adapted to receive a mixed gas to be separated and having a cylindrical wall with disc members positioned at either end thereof, said drum driven at a high rotational speed;
a pair of shafts mounted to said disc members along an axis of said drum;
bearing means for rotatably supporting said shafts within said housing;
exhaust means for exhausting separated gases;
one of said shafts being hollow for passing said mixed gas to be separated into said drum,
supply means for feeding said mixed gas flowing through said hollow shaft into said drum, near the periphery of said cylindrical wall, wherein said supply means comprises at least one conduit provided in housing;
means for feeding said mixed gas to be separated into said drum means at at least one position which is at an intermediate portion thereof and is a radial distance from the axis of said drum means; and,
exhaust means for exhausting separated gases, said exhaust means located nearer said axis than said feeding means, or creating a radially inward gas flow whereby said mixed gas attains a higher rotational speed than said drum means.

7. A centrifugal gas separator according to claim **6,** wherein said supply means comprises:

at least one conduit provided in one of said disc members which is secured to said hollow shaft; and,

an inner cylindrical member mounted inside said cylindrical wall of said drum to form a passage between said cylindrical member and said cylindrical wall, said passage communicating with said conduit.

8. A centrifugal gas separator according to claim **6**, wherein:

the axial length of said inner cylindrical member is approximately one half that of said drum.

* * * * *