

US 6,565,626 B1 and US 6,168,649 B1 each disclose membrane separation processes with three membrane separation stages, wherein a retentate stream and a permeate stream from stages 2 and 3 respectively are recycled to the crude gas stream.

A disadvantage of the processes known from the prior art is that either a high purity of the permeate gas or a high purity of the retentate gas can be achieved. For the simultaneous achievement of high purities of permeate gas and retentate gas, as necessary, for example, in the processing and feeding of biogas into the natural gas grid as a result of the high demands on the methane purity and as a result of the limitation of methane slippage, there are no processes which do not need a recompression unit or a further purification of the permeate or retentate stream (for example thermal postcombustion of the permeate stream or pressure swing adsorption for the retentate stream).

Proceeding from this prior art, it was an object of the present embodiments disclosed herein~~invention~~ to provide apparatuses and processes for separation and purification of gas mixtures, which have the disadvantages of the prior art processes and apparatuses only to a reduced degree, if at all. More particularly, processes and apparatuses which afford both permeate gas and retentate gas are to be provided in high purities. In a further specific object, this process and this apparatus are to be advantageous in terms of investment and operating costs and/or enable a simpler process regime.

In a next specific object, a process/apparatus usable with maximum universality is to be provided for any desired gas mixtures. More particularly, it should be possible to separate gas streams which are obtained in the production of biogas and natural gas, or which

comprise carbon dioxide and methane in the presence of other gases such as water, hydrogen, hydrogen sulfide.

It was a further specific object of the present embodiments disclosed herein ~~invention~~ to provide a process or an apparatus which enables purification of methane-containing crude gas streams, with reduced methane emission compared to the prior art processes at the same throughput, and hence reduced environment pollution by this strong greenhouse gas.

In one aspect, there is provided an apparatus for separating gases, comprising: membrane separation stages; and,

a compressor, a vacuum pump, or both,

wherein the membrane separation stages comprise a feed stream separation stage, a retentate separation stage, and a permeate separation stage:

the feed stream separation stage is configured to separate a feed stream comprising at least two components into a first permeate stream and a first retentate stream,

the retentate separation stage is configured to divide the first retentate stream into a second permeate stream and a second retentate stream,

wherein

the second permeate stream is supplied to the feed stream, and the second retentate stream is withdrawn as a product, and

the permeate separation stage is configured to divide the first permeate stream into a third retentate stream and a third permeate stream,

wherein

the third retentate stream is supplied to the feed stream, and the third permeate stream is withdrawn as a product,

the apparatus is configured not to subject the first permeate stream to any recompression,

the feed stream separation stage comprises a gas separation membrane module having a mixed gas selectivity of at least 30,

the apparatus is configured such that a gas volume recycled in the second permeate stream and in the third retentate stream totals less than 60% by volume of a crude gas stream,

the apparatus is configured to increase a concentration of at least one permeate gas of the feed stream separation stage, after recycling of the second permeate stream and of the third retentate stream, in the feed stream, compared to a concentration in the crude gas stream.

In another aspect, there is provided a process for separating a gas mixture stream comprising: separating the gas mixture with an apparatus comprising:

membrane separation stages; and

a compressor, a vacuum pump, or both,

wherein the membrane separation stages comprise a feed stream separation stage, a retentate separation stage, and a permeate separation stage:

the feed stream separation stage is configured to separate the gas mixture stream into a first permeate stream and a first retentate stream,

the retentate separation stage is configured to divide the first retentate stream into a second permeate stream and a second retentate stream,

wherein the second permeate stream is supplied to the gas mixture stream, and the second retentate stream is withdrawn as a product, and the permeate separation stage is configured to divide the first permeate stream into a third retentate stream and a third permeate stream,

wherein the third retentate stream is supplied to the gas mixture stream, and the third permeate stream is withdrawn as a product,

the apparatus is configured not to subject the first permeate stream to any recompression,

the feed stream separation stage comprises a gas separation membrane module having a mixed gas selectivity of at least 30,

the apparatus is configured such that a gas volume recycled in the second permeate stream and in the third retentate stream totals less than 60% by volume of a crude gas stream,

the apparatus is configured to increase a concentration of at least one permeate gas of the feed stream separation stage, after recycling of the second permeate stream and of the third retentate stream, in the feed stream, compared to a concentration in the crude gas stream, and

wherein the third permeate stream comprises more than 95 vol% of a retentate gas of the feed stream separation stage in the gas mixture stream, and the second retentate system comprises more than 95 vol% of a permeate gas of the feed stream separation stage in the gas mixture stream.

In another aspect, there is provided a process for separating a gas mixture stream comprising methane and carbon dioxide, comprising:

separating the gas mixture with an apparatus comprising:

membrane separation stages; and,

a compressor, a vacuum pump, or both,

wherein the membrane separation stages comprise a feed stream separation stage, a retentate separation stage, and a permeate separation stage:

the feed stream separation stage is configured to separate a feed stream comprising at least two components into a first permeate stream and a first retentate stream,

the retentate separation stage is configured to divide the first retentate stream into a second permeate stream and a second retentate stream,

wherein the second permeate stream is supplied to the feed stream, and the second retentate stream is withdrawn as a product, and

the permeate separation stage is configured to divide the first permeate stream into a third retentate stream and a third permeate stream.

wherein the third retentate stream is supplied to the feed stream, and the third permeate stream is withdrawn as a product,

the apparatus is configured not to subject the first permeate stream to any recompression,

the feed stream separation stage comprises a gas separation membrane module having a mixed gas selectivity of at least 30,

the apparatus is configured such that a gas volume recycled in the second permeate stream and in the third retentate stream totals less than 60% by volume of a crude gas stream,

the apparatus is configured to increase a concentration of at least one permeate gas of the feed stream separation stage, after recycling of the second permeate stream and of the third retentate stream, in the feed stream, compared to a concentration in the crude gas stream.

Further objects which are not stated explicitly are evident from the overall context of the claims, description, examples and figures which follow.

It has now been found that, surprisingly, the apparatus according to claim 1 or one of the claims dependent thereon can afford pure streams of permeate and retentate without requiring more than one compressor or any need to purify the permeate or retentate stream further by other methods. The inventive apparatus thus enables simultaneous achievement of permeate and retentate streams in high purity. The capital costs for the plant are low; it does not need any additional downstream purification processes. It was thus possible to achieve the stated objects with a pure membrane separation process.

The present claims therefore provide the apparatus and process claimed in claims 1 to 12 and 13 to 18 respectively, and defined in detail in the description, examples and figure 11 which follow.

The present ~~disclosureinvention~~ is described in detail hereinafter. First, some important terms are defined.

The quotient of the permeances of the individual gases gives the **selectivity** of the membrane for separation