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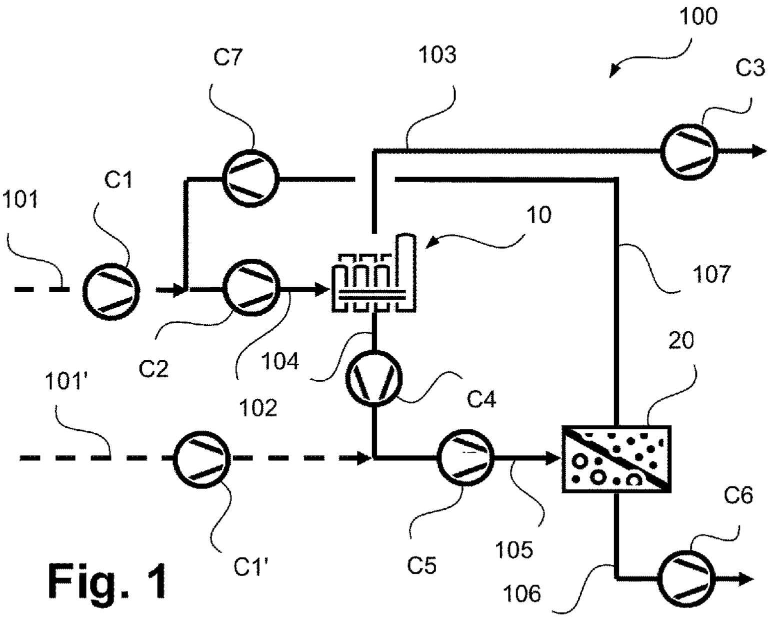

Fig. 1

(57) Abstract: A method (100, 200, 300) for separating hydrogen from methane in a component mixture (101) containing light components is provided, the light components including hydrogen, methane and preferably at least one further component selected from methane, nitrogen, carbon monoxide and oxygen, wherein a pressure swing adsorption feed stream (102) is formed at a first pressure level, wherein the pressure swing adsorption feed stream (102) is subjected to a pressure swing adsorption step (10), wherein a high-pressure product (103) at the first pressure level and a low-pressure product (104) at a second pressure level below the first pressure level are withdrawn from the pressure swing adsorption step (10), wherein a membrane feed stream (105) is formed at a third pressure level at or above the second pressure level using the low-pressure product (104) or a part thereof, wherein the membrane feed stream is subjected to a membrane separation step (20), wherein a retentate (106) at the third pressure level and a permeate (107) at a fourth

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pressure level below the third pressure level are withdrawn from the membrane separation step (20), wherein the pressure swing adsorption feed stream (102) is formed using the permeate (107) or a part thereof, and wherein the pressure swing adsorption feed stream (102) and/or the membrane feed stream (105) is formed using the component mixture (101) or a part thereof. An apparatus is also part of the present invention.

Description

Method and apparatus for separating a component mixture

The present invention relates to a method and to an apparatus for separating a component mixture containing light components.

Background

Very light components such as hydrogen can be recovered from gas mixtures using pressure swing adsorption (PSA) with very high purity. In pressure swing adsorption, separation is achieved based on the different adsorption forces of the components to be separated using a cyclic pressure change. Substances that adsorb well to an adsorbent are retained thereon in a step or phase wherein the gas mixture to be separated is passed over the adsorbent at a high pressure (“adsorption phase”). In a subsequent step or phase, these substances are removed from the adsorbent essentially by a pressure relief (“desorption phase”).

Accordingly, there is a high-pressure product obtained in the adsorption phase, typically comprising components with very low boiling points, and a low-pressure product (also called pressure swing adsorption tailgas) obtained in the desorption phase, typically comprising components with higher boiling points.

For further details, reference is made to expert literature, such as the article “Hydrogen, 3. Purification” by Peter Häussinger, Reiner Lohmüller and Allan M. Watson in Ullmann’s Encyclopedia of Industrial Chemistry, first published on 15 October 2011, https://doi.org/10.1002/14356007.o13_o04.

Using a pressure swing adsorption step without further process steps, it is possible, for example, to extract from a feed gas mixture provided at 30 bar (abs.) high purity hydrogen with e.g. 99.999 mol% hydrogen content at a similar pressure level (high-pressure product). The remaining components of the gas mixture (including non-recovered hydrogen) may be obtained at a lower pressure, for example at a pressure of 5 bar (abs.) (low-pressure product).

Table 1 lists adsorption forces, boiling points and molecular masses for selected substances that may at least in part be included in component mixtures according to embodiments of the present invention.

Table 1

Component	**Adsorption force**	**Boiling point [K] at 1 bar (abs.)**	**Molecular mass (rounded)**
He		4	4
H_2	Very weak	20	2
N_2		77	28
CO	Medium	82	28
O_2		90	32
CH_4	Medium	111	16
C_2H_6	Strong	184	30
CO_2	Strong	195 (subl.)	44
C_3H_8	Strong	231	44
H_2O	Very strong	373	18

Pressure swing adsorption may have the disadvantage that the yield of the component to be recovered at the high pressure, for example hydrogen, can be quite low, for example only 70 to 90%. At the same time, substantial amounts of the component to be recovered at high pressure are also still present in the pressure swing adsorption tail gas, i.e. the concentration of the light boiling component in the pressure swing adsorption tail gas can still be high.

Various processes have been developed to improve the purity of pressure swing adsorption tail gas. Reference is e.g. made to US 3,838,553 A. Such processes include compression of the low-pressure product and cryogenic separation and/or partial condensation, as well as recycling of the non-condensed components to the pressure swing adsorption step. Such methods work particularly well when the products to be separated have very widely separated boiling points, or generally if the components to be separated from the target compound have comparatively higher boiling points. This applies, for example, to the separation of hydrogen from the components ethane, carbon dioxide and/or propane. However, if the components to be separated from the high-pressure product also have a low boiling point, such as nitrogen, carbon monoxide, oxygen or methane, cryogenic separation has generally proven to be costly and/or difficult.

The present invention has the object to improve separation, using pressure swing adsorption, of a light component, such as hydrogen, from a corresponding component mixture including further light components.

Disclosure of the invention

Against this background, a method and an apparatus for separating a component mixture containing light components comprising the features of the independent claims is provided. Preferred embodiments of the invention are the subject of the dependent claims and of the description that follows.

According to the present invention, a method for separating hydrogen from methane in a component mixture containing light components is provided, the light components including hydrogen, methane and preferably at least one further component selected from nitrogen, carbon monoxide and oxygen, wherein a pressure swing adsorption feed stream is formed at a first pressure level, wherein the pressure swing adsorption feed stream is subjected to a pressure swing adsorption step, wherein a high-pressure product at the first pressure level and a low-pressure product at a second pressure level below the first pressure level are withdrawn from the pressure swing adsorption step, wherein a membrane feed stream is formed at a third pressure level at or above the second pressure level using the low-pressure product or a part thereof, wherein the membrane feed stream is subjected to a membrane separation step, wherein a retentate at the third pressure level and a permeate at a fourth pressure level below the third pressure level are withdrawn from the membrane separation step, wherein the pressure swing adsorption feed stream is formed using the permeate or a part thereof, and wherein the pressure swing adsorption feed stream and/or the membrane feed stream is formed using the component mixture or a part thereof.

If hereinbelow, reference is made to a feed stream “being formed” using one stream, this is not intended to exclude that such a stream is not formed using a further stream as well. In embodiments of the present invention, for example, the pressure swing adsorption feed stream may be formed using the permeate stream or a part thereof, and optionally the component mixture or a part thereof, and the membrane feed stream may be formed using the formed using the low-pressure product or a part thereof and optionally the component mixture or a part thereof. That is, the component mixture may be completely or in part be combined with the permeate stream or a part thereof to form the pressure swing adsorption feed stream, while the membrane feed stream is not formed by combining the component mixture or a part thereof and the low-pressure product or a part thereof. In an alternative, the component mixture may be completely or in part be combined with the low-pressure product or a part thereof to form the membrane feed stream while the pressure swing adsorption feed stream is not formed by combining the component mixture or a part thereof and the low-pressure product or a part thereof. In a further alternative, a part of the component mixture may be combined with the permeate or a part thereof to form the pressure swing adsorption feed stream and a further part of the component mixture may be combined with the low-pressure product or a part thereof to form the membrane feed stream.

Herein, the term “pressure level” is used in order to express that no exact pressures but pressure ranges can be used in order to realise the present invention and advantageous embodiments thereof. Different pressure levels may lie in distinctive ranges or in ranges overlapping each other. They also cover expected and unexpected, particularly unintentional, pressure changes, e.g. inevitable pressure or temperature losses. Values expressed for pressure levels in bar units are generally absolute pressure values (bar abs.).

In methods according to embodiments of the present invention, a pressure swing adsorption step and a membrane separation step may each can be realized using corresponding units of a plurality of sub-units such as adsorber vessels or membrane cartridges and associated apparatus as known to the skilled person. The pressure swing adsorption step may also be performed at least in part as a vacuum pressure swing adsorption step wherein the low-pressure product is obtained at a sub-atmospheric pressure level.

The proposed method overcomes the problems of low product purity of a pressure swing adsorption tail gas or low yield of the pressure swing adsorption high pressure product as discussed above. In embodiments of the present invention, an interconnection of a pressure swing adsorption step with a membrane separation step increases the yield of the pressure swing adsorption high pressure product and at the same time increases the purity of the product with the higher boiling components. For example, by interconnecting the pressure swing adsorption step with the membrane separation step, a higher overall yield of hydrogen is achieved, even though the pressure swing adsorption only provides a yield of 85%, for example.

Depending on the objective, the composition of the compositions to be treated according to the present invention can be different, as explained below. The present invention is advantageous over the prior art, such as e.g. the process described in US 3,838,553 A, for example, as it is substantially less complex for the separation of light and very light boiling components and is less apparatus and in some examples less energy intensive.

In an embodiment of the present invention, the component mixture may contain less than 90 mol% of hydrogen and methane and may further contain at least one further component selected from nitrogen, carbon monoxide and oxygen. Particularly, such a component mixture may be a so-called tail gas from a cryogenic separation train of a steamcracker unit, a synthesis gas or a different gas mixture having a similar composition.

In an embodiment of the present invention, however, a common content of hydrogen and methane in the component mixture is more than 95 mol%, more than 98 mol% or more than 99 mol%. This is what is meant below if reference is made to a mixture comprising “essentially” hydrogen and methane. Particularly, such a component mixture may particularly a tail gas from a separation train of a steamcracker as mentioned above or a different gas mixture having a similar composition. The remainder not included in common content of hydrogen and methane may e.g. include carbon monoxide, carbon dioxide, and hydrocarbons heavier than methane.

In such an embodiment, a content of hydrogen in the component mixture may be 5 to 95 mol% and the content of methane in the component mixture may be the remainder of the common content of hydrogen and methane in the component mixture. The hydrogen content may e.g. be 70 to 90 mol%, particularly at or around 80 mol%, and the methane content may be 15 to 25 mol%, particularly at or around 19 mol%. The high pressure product may comprise hydrogen in a content of 90 to 100 mol%, e.g. at or around 99% or 99.995 mol%.

In an embodiment of the present invention, the third pressure level may be at the second pressure level, particularly if the first pressure level is sufficiently high and/or the pressure swing adsorption step is performed such in a manner suitable to provide the low-pressure product thereof at a sufficiently high pressure for being passed to the membrane separation step without further compression. A corresponding embodiment of the present invention may thus dispense of a compressor for compressing the low-pressure product of the pressure swing adsorption step, but a compressor for compressing the permeate to be recycled to the pressure swing adsorption step may be required.

In such an embodiment of the present invention, the first pressure level may be 20 to 40 bar abs., e.g. at or around 30 bar abs., the second and the third pressure level may be 3 to 10 bar abs., e.g. at or around 5 bar abs., and the fourth pressure level may be 0.5 to 1.5 bar abs., e.g. at or around 1 bar abs.

In an alternative embodiment of the present invention, the third pressure level may, however, also be above the second pressure level, particularly if the first pressure level the pressure swing adsorption step is, or may not be, performed such as to provide the low-pressure product thereof at a sufficiently high pressure for being passed to the membrane separation step without further compression. A corresponding embodiment of the present invention may thus include a compressor for compressing the low-pressure product of the pressure swing adsorption step, but a compressor for compressing the permeate to be recycled to the pressure swing adsorption step may be omitted.

In such an embodiment of the present invention, the first pressure level may be 3 to 10 bar abs., e.g. at or around 5 bar abs., the second pressure level may be 0.5 to 1.5 bar abs., e.g. at or around 1 bar abs., the third pressure level may be 20 to 30 bar abs., e.g. at or around 25 bar abs., and the fourth pressure level may be 3 to 10 bar abs., e.g. at or around 5 bar abs.

In embodiments of the present invention, the retentate or a part thereof may be passed to a further processing step such as a reforming step, and the high-pressure product or a part thereof may be passed to a combustion step or a different use, depending on its purity, in particular.

In embodiments of the present invention, at least one of the component mixture or a part thereof, the adsorption feed stream or a part thereof, the high-pressure product or a part thereof, the low-pressure product or a part thereof, the membrane feed stream or a part thereof, the retentate or a part thereof, and the permeate or a part thereof may be subjected one or more compression steps. That is, all feed and/or product streams may be subjected to compression, if needed, and depending on required conditions inside and outside the process or apparatus.

In embodiments of the present invention, any compression step, i.e. the or at least one of the compression steps just mentioned, may be performed using at least one of a piston compressor, a screw compressor and a turbo compressor and/or using mechanical energy produced in an expansion step to which any of the feed and/or product streams may be subjected, or at least two of the compression steps may be performed using a common machine including e.g. different turbo wheels.

In embodiments of the present invention, any further method steps may be included, i.e. at least one step selected from a heat exchange step, a cooling step, a cryogenic separation or distillation step, a temperature swing adsorption or drying step, a reforming step, a shifting step, a hydrogenation step, an absorptive or scrubbing step, a further membrane separation step and a further pressure swing adsorption step.

An apparatus for separating a component mixture containing light components is also part of the present invention, the light components including hydrogen, methane and preferably at least one further component selected from methane, nitrogen, carbon monoxide and oxygen, wherein the apparatus includes means configured to perform a pressure swing adsorption step and a membrane separation step, to form a pressure swing adsorption feed stream at a first pressure level, to subject the pressure swing adsorption feed stream to the pressure swing adsorption step, to withdraw a high-pressure product at the first pressure level and a low-pressure product at a second pressure level below the first pressure level from the pressure swing adsorption step, to form a membrane feed stream at a third pressure level at or above the second pressure level using the low-pressure product or a part thereof, to subject the membrane feed stream to the membrane separation step, to withdraw a retentate at the third pressure level and a permeate at a fourth pressure level below the third pressure level from the membrane separation step, to form the pressure swing adsorption feed stream using the permeate or a part thereof, and to form the pressure swing adsorption feed stream and/or the membrane feed stream using the component mixture or a part thereof.

As to specific further features and embodiments of such an apparatus, reference is made to the explanations above relating to the method according to the invention and its advantageous embodiments. This equally applies for a corresponding apparatus which is adapted to perform a corresponding method or one of its embodiments. Such an apparatus may particularly include a control unit programmed or adapted to control the apparatus accordingly.

Short description of the Figures

Figures 1 to 3 illustrate embodiments of methods provided according to the present invention in the form of simplified process flow or block diagrams.

Embodiments of the present invention

In Figures 1 to 3, embodiments of methods provided according to the present invention are illustrated and designated 100, 200 and 300, respectively. In these methods, a pressure swing adsorption step 10 and a membrane separation step 20 are used, which each can be realized using corresponding units of a plurality of sub-units such as adsorber vessels or membrane cartridges and associated apparatus. If reference is made to method steps, the corresponding explanations likewise apply to such units or sub-units used in a corresponding method and vice versa.

In all cases shown, the methods 100, 200 and 300, a component mixture 101 containing light components as mentioned above and further explained below is provided. A pressure swing adsorption feed stream 102 is formed at a first pressure level as indicated below. The pressure swing adsorption feed stream 102 is subjected to the pressure swing adsorption step 10, and a high-pressure product 103 at the first pressure level and a low-pressure product 104 at a second pressure level below the first pressure level are withdrawn from the pressure swing adsorption step 10.

A membrane feed stream 105 is formed at a third pressure level at or above the second pressure level using the low-pressure product 104 or a part thereof, and the membrane feed stream is subjected to a membrane separation step 20. A retentate 106 at the third pressure level and a permeate 107 at a fourth pressure level below the third pressure level are withdrawn from the membrane separation step 20. The pressure swing adsorption feed stream 102 is formed using the permeate 107 or a part thereof. As illustrated in Figure 1, the component mixture 101 may used, at least in part(s), in forming the pressure swing adsorption feed stream 102 and/or the membrane feed stream 105 (as indicated with 101'), as explained in detail above. A single, common, or separate compression C1 (and C1') may be performed. These alternatives may, albeit not explicitly illustrated, be part of the embodiments illustrated in Figures 2 and 3 as well.

As illustrated in Figure 1, in the method 100, the component mixture 101 (and/or 101') may e.g. be a tail gas from a steamcracking unit containing hydrogen and methane or a similar gas mixture. As illustrated for the alternative in which a part or all of the component mixture 101 is used in forming the pressure swing adsorption feed 102, this, or this part, of the component mixture 101 may be compressed using the compressor C1 is then combined with the permeate 107 or a part thereof, which may itself have been compressed using a compressor C7, while a further compression may be performed in a compressor C2 to form the pressure swing adsorption feed stream 102.

The low-pressure product 104 or a part thereof may be compressed using a compressor C4. After the low-pressure product 104 or a part thereof compressed using the compressor C4 is combined (in the alternative illustrated above) with the, or a part of, the component mixture C1', which may itself have been compressed using a compressor C1', a further compression can be performed in a compressor C5 to form the membrane feed stream 105.

The high-pressure product 103, containing light components such as hydrogen, nitrogen, carbon monoxide and oxygen, may be provided as a product of the method 100 and may be further compressed using a compressor C3. The retentate 106, containing methane, and a small part of some of the light components, such as nitrogen, carbon monoxide, oxygenand hydrocarbons with more than one carbon atom, may be withdrawn from method 100 and may be further compressed using a compressor C6.

As illustrated in Figure 2, in the method 200, the component mixture 101, which may e.g. be a tail gas from a steamcracking unit containing essentially hydrogen and methane, or a similar gas mixture, may be used completely for forming the pressure swing adsorption feed stream 102 (although the options illustrated in Figure 1 are generally possible here as well). In the method 200, compressors C1 to C6 shown in Figure 1, which are not illustrated in Figure 2, may be present or may be selectively omitted. In this example, membrane feed stream 105 is particularly formed at the third pressure level which is here at the second pressure level. In this example, the first pressure level may be at or around 30 bar (abs.), the second and third pressure levels may be at or around 5 bar (abs.), and the fourth pressure level may be at or around 1 bar (abs.).

The high-pressure product 103, containing, in the method 200, essentially hydrogen, may be provided as a product of the method 200 and the retentate 106, containing essentially methane, may be withdrawn from method 200.

In method 200 illustrated in Figure 2, the component mixture 101 may particularly be provided containing predominantly hydrogen (5 to 95 mol%, e.g. 80 mol%), methane (5 to 95 mol%, e.g. 19 mol%), and small amounts of other hydrocarbons (0 to 10 mol%, e.g. 1 mol%). This component mixture 101 may be provided at or around 30 bar (abs.), as mentioned. Separation by pressure swing adsorption occurs and hydrogen is recovered, in the high-pressure product 103, at or around 30 bar (abs.), with a purity of 90 to 100 mol% (e.g. 99.995 mol%) and a yield of 60 to 95% (e.g. 85%). A pressure swing adsorption tailgas stream, i.e. the low pressure product 104, is present at or around 5 bar (abs.), as mentioned, and contains the remaining hydrogen, as well as methane and other hydrocarbons. The membrane separation step 20 is performed and the retentate 106 is produced at or around 5 bar (abs.), as mentioned, which contains only a small amount of hydrogen (e.g. 2 mol%). The remaining gas, i.e. the permeate 107, contains predominantly hydrogen as well as certain amounts of methane and is present at or around 1 bar (abs.), as mentioned. Finally, a compression using compressor C7 to at or around 30 bar (abs.) is performed, as also mentioned, and the permeate 107 is fed to the pressure swing adsorption together with the component mixture 101.

By interconnecting the pressure swing adsorption step 10 with the membrane separation step 20, a higher overall yield of hydrogen is achieved, although the pressure swing adsorption only provides a yield of, for example, 85%.

Also in the method 300 illustrated in Figure 3, the component mixture 101, which may e.g. be a tail gas from a steamcracking unit containing essentially hydrogen and methane, or a similar gas mixture, may be used completely for forming the pressure swing adsorption feed stream 102 (although the options illustrated in Figure 1 are generally possible here as well). In the method 300, compressors C1 to C3 and C5 to C7 shown in Figure 1, which are not illustrated in Figure 3, may be present or may be selectively omitted. In this example, membrane feed stream 105 is particularly formed at the third pressure level which is here above the second pressure level using compressor C5. In this example, the first pressure level may be at or around 5 bar (abs.), the second pressure level may be at or around 1 bar (abs.), the third pressure level may be at or around 25 bar (abs.), and the fourth pressure level may be at or around 5 bar (abs.).

As explained for method 200, the high-pressure product 103, containing, in the method 300, essentially hydrogen, may be provided as a product of the method 300 and the retentate 106, containing essentially methane, may be withdrawn from method 300.

In method 200 illustrated in Figure 2, the component mixture 101 may particularly be provided containing predominantly hydrogen (5 to 95 mol%, e.g. 80 mol%), methane (5 to 95 mol%, e.g. 19 mol%) and small amounts of other hydrocarbons (0 to 10 mol%, e.g. 1 mol%). This component mixture 101 may be provided at or around 5 bar (abs.), as mentioned. Separation is, as above, initially performed by pressure swing adsorption and hydrogen is obtained, in the high-pressure product 103 at about 5 bar (abs.), as mentioned, with a purity of 90 to 100 mol% (e.g. 99 mol%) and a yield of 60 to 95% (e.g. 85%). This hydrogen is suitable for low carbon dioxide combustion in a steamcracker, for example. The pressure swing adsorption tailgas stream, i.e. the low-pressure product 104, is present at or around 1 bar (abs.), as mentioned, and contains the remaining hydrogen, as well as methane and other hydrocarbons. Finally, a compression using compressor C4 at or around 25 bar (abs.) is performed, and a separation by means of membrane separation step 20 is performed. The retentate 106 is generated at or around 25 bar (abs.), as mentioned, which contains only a small amount of hydrogen (e.g. 2 mol%). This methane-rich stream is suitable for use in a synthesis gas process. The synthesis gas process can include an autothermal reforming as well as a CO shift and a CO2 separation, with the aim to produce hydrogen. The residual gas from the membrane separation step 20, i.e. permeate 107, contains predominantly hydrogen as well as certain amounts of methane and is present at about 5 bar (abs.), as mentioned. The permeate 107 is fed to the pressure swing adsorption together with the component mixture 101.

For the avoidance of doubt, the present invention is not limited to the embodiments shown in Figures 1 to 3 but limited by the claims. A plurality of variations of the embodiments shown in the Figures is envisaged by the present invention. For the separation of methane and higher hydrocarbons (particularly hydrocarbons with two carbon atoms, for example), there may be different feed concentrations and therefore requirements as to feed and product pressure(s). These requirements essentially determine at which positions the compression steps are performed and whether a compression is made at different positions.

Patent Claims

1. A method (100, 200, 300) for separating hydrogen from methane in a component mixture (101) containing light components, the light components including hydrogen and methane, wherein a pressure swing adsorption feed stream (102) is formed at a first pressure level, wherein the pressure swing adsorption feed stream (102) is subjected to a pressure swing adsorption step (10), wherein a high-pressure product (103) at the first pressure level and a low-pressure product (104) at a second pressure level below the first pressure level are withdrawn from the pressure swing adsorption step (10), wherein a membrane feed stream (105) is formed at a third pressure level at or above the second pressure level using the low-pressure product (104) or a part thereof, wherein the membrane feed stream is subjected to a membrane separation step (20), wherein a retentate (106) at the third pressure level and a permeate (107) at a fourth pressure level below the third pressure level are withdrawn from the membrane separation step (20), wherein the pressure swing adsorption feed stream (102) is formed using the permeate (107) or a part thereof, and wherein the pressure swing adsorption feed stream (102) and/or the membrane feed stream (105) is formed using the component mixture (101) or a part thereof.

2. The method (100) according to claim 1, wherein the component mixture (101) contains less than 90 mol% of hydrogen and methane and further contains at least one further component selected from nitrogen, carbon monoxide and oxygen.

3. The method (200, 300) according to claim 1, wherein a common content of hydrogen and methane in the component mixture (101) is more than 95 mol%, more than 98 mol% or more than 99 mol%.

4. The method (200, 300) according to claim 2, wherein a content of hydrogen in the component mixture (101) is 5 to 95 mol% and wherein the content of methane in the component mixture (101) is the remainder of the common content of hydrogen and methane in the component mixture (101).

5. The method (200) according to any one of claims 3 or 4, wherein the third pressure level is at the second pressure level.

6. The method (200) according to claim 5, wherein the first pressure level is 20 to 40 bar abs., the second and the third pressure level is 3 to 10 bar abs. and the fourth pressure level is 0.5 to 1.5 bar abs.

7. The method (300) according to any one of claims 3 or 4, wherein the third pressure level is above the second pressure level.

8. The method (300) according to claim 7, wherein the first pressure level is 3 to 10 bar abs., the second pressure level is 0.5 to 1.5 bar abs., the third pressure level is 20 to 30 bar abs. and the fourth pressure level is 3 to 10 bar abs.

9. The method (200, 300) according to any one of claims 3 to 8, wherein the retentate (106) or a part thereof is passed to a reforming step.

10. The method (200, 300) according to any one of claims 3 to 8, wherein the high-pressure product (103) or a part thereof are passed to a combustion step.

11. The method (100, 200, 300) according to any of the preceding claims, wherein at least one of the component mixture (101) or a part thereof, the adsorption feed stream (102) or a part thereof, the high-pressure product (103) or a part thereof, the low-pressure product (104) or a part thereof, the membrane feed stream (105) or a part thereof, the retentate (106) or a part thereof, and the permeate (107) or a part thereof are subjected one or more compression steps.

12. The method (100, 200, 300) according to claim 11, wherein the compression step or at least one of the compression steps is performed using at least one of a piston compressor, a screw compressor and a turbo compressor and/or using mechanical energy produced in an expansion step, or wherein at least two of the compression steps are performed using a common machine.

13. The method (100, 200, 300) according to any one of the preceding claims, further including at least one step selected from a heat exchange step, a cooling step, a cryogenic separation or distillation step, a temperature swing adsorption or drying step, a reforming step, a shifting step, a hydrogenation step, an absorptive or

scrubbing step, a further membrane separation step and a further pressure swing adsorption step.

14. An apparatus for separating hydrogen from methane in a component mixture (101) containing light components, the light components including hydrogen and methane, wherein the apparatus includes means configured to perform a pressure swing adsorption step (10) and a membrane separation step, to form a pressure swing adsorption feed stream (102) at a first pressure level, to subject the pressure swing adsorption feed stream (102) to the pressure swing adsorption step (10), to withdraw a high-pressure product (103) at the first pressure level and a low-pressure product (104) at a second pressure level below the first pressure level from the pressure swing adsorption step (10), to form a membrane feed stream (105) at a third pressure level at or above the second pressure level using the low-pressure product (104) or a part thereof, to subject the membrane feed stream to the membrane separation step (20), to withdraw a retentate (106) at the third pressure level and a permeate (107) at a fourth pressure level below the third pressure level from the membrane separation step (20), to form the pressure swing adsorption feed stream (102) using the permeate (107) or a part thereof, and to form the pressure swing adsorption feed stream (102) and/or the membrane feed stream (106) using the component mixture (101) or a part thereof.

15. The apparatus according to claim 14, further comprising means configured to perform a method (100, 200, 300) according to any one of claims 1 to 13.

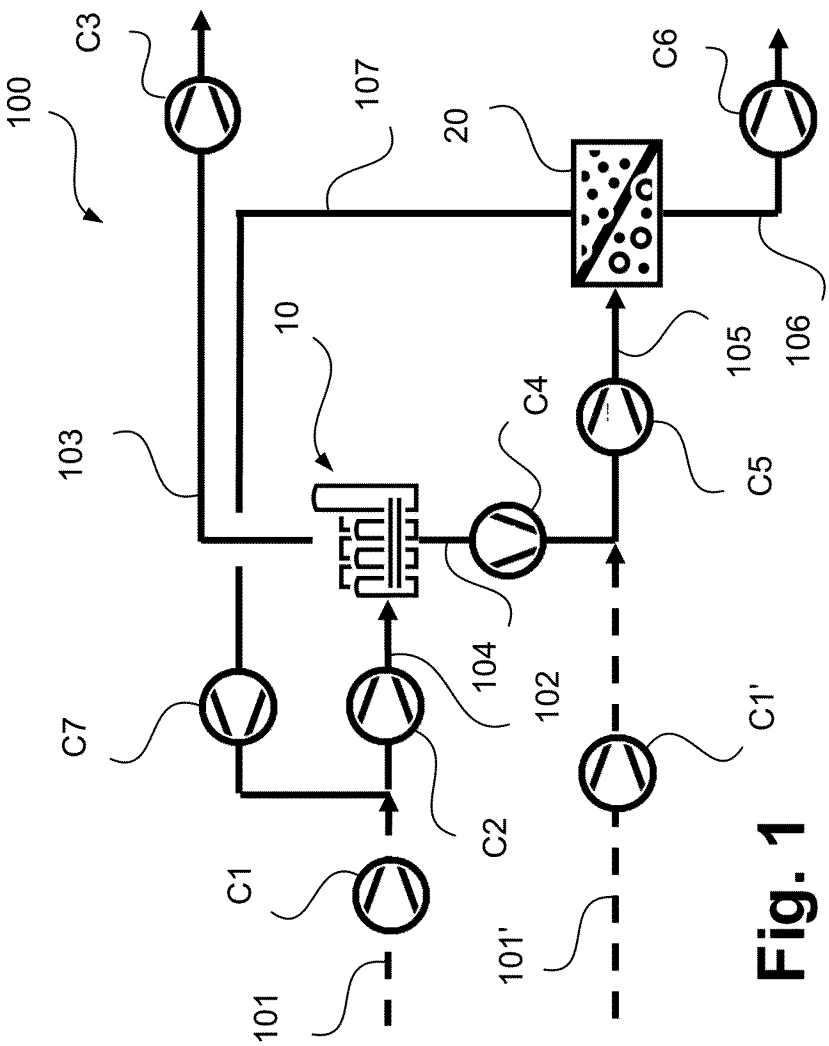

Fig. 1

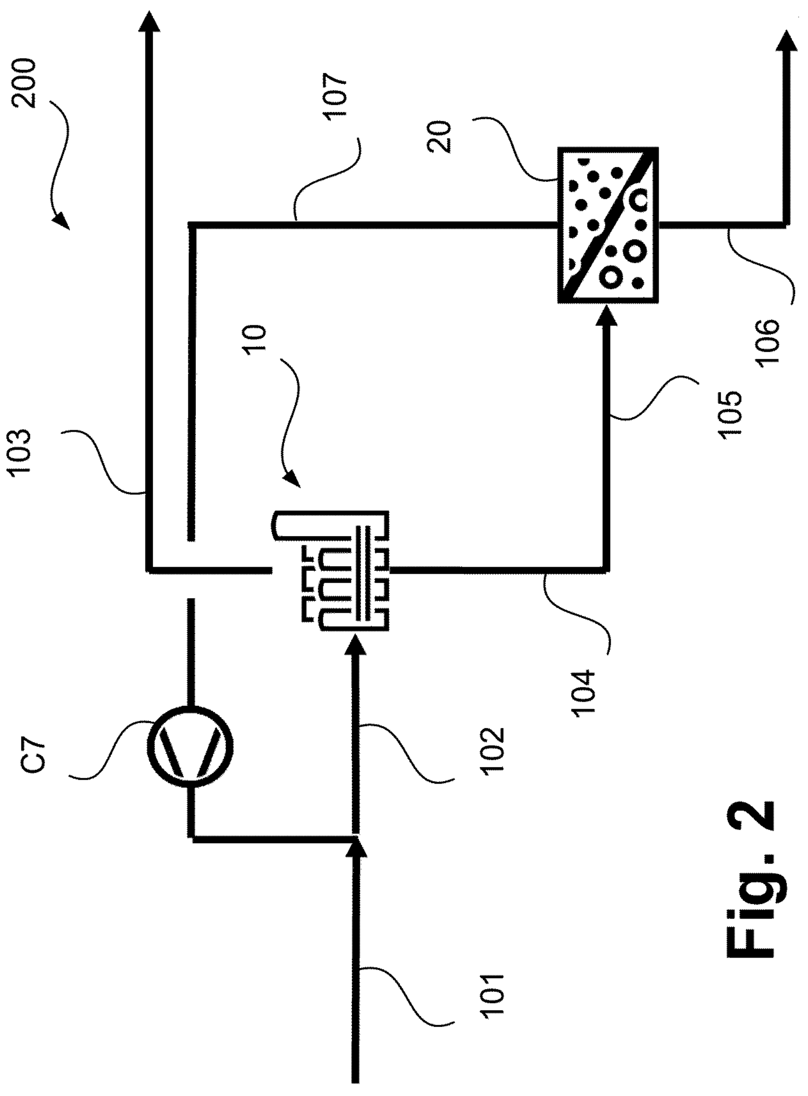

Fig. 2

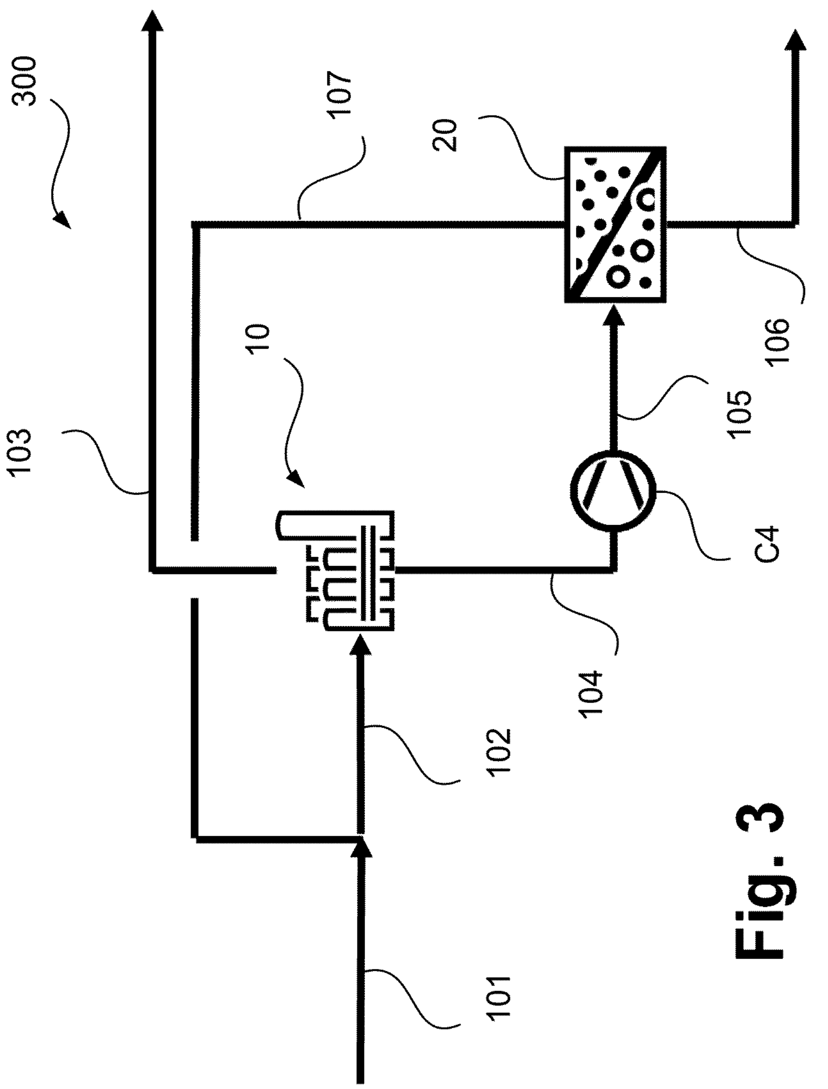

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/025109

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01D53/047 B01D53/22 C01B3/50 C01B3/56
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01D C01C C01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2010/129284 A1 (NIITSUMA TAKUYA [JP] ET AL) 27 May 2010 (2010-05-27) paragraphs [0024], [0032]; figures 2,4; tables B4,C4 -----	1-3,5, 10-15 4
X Y	US 2012/121497 A1 (TERRIEN PAUL [US] ET AL) 17 May 2012 (2012-05-17) paragraphs [0015], [0018]; figure 5 -----	1-3,5-9, 14,15 4
X Y	US 2012/241678 A1 (VALENTIN SOLENE [FR] ET AL) 27 September 2012 (2012-09-27) figure 1 -----	2,3,5-15 4
Y	US 2013/197285 A1 (SHAFI RAHEEL [SA] ET AL) 1 August 2013 (2013-08-01) figure 1 -----	4

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 June 2023	04/08/2023

Name and mailing address of the ISA/
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Authorized officer
de Biasio, Arnaldo

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2023/025109

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:

1-15(partially)

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-15(partially)

The method of claim 1 and the apparatus of claim 14 wherein the pressure swing adsorption feed stream is formed using the component mixture or a part thereof.

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2. claims: 1-15(partially)

The method of claim 1 and the apparatus of claim 14 wherein the membrane feed stream is formed using the component mixture or a part thereof.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2023/025109

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