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(54) **Title:** PROCESS AND APPARATUS FOR THE SEPARATION OF CARBON DIOXIDE AND HYDROGEN

(57) **Abstract:** The present invention is directed to a separation process and apparatus, wherein CO₂ is separated from a gaseous feed stream comprising CO₂ and H₂, and comprises the steps of: (i)cooling and partially condensing the feed stream; (ii)passing the cooled and partially condensed feed stream from step (i) to a first vapour-liquid separator to produce a vapour stream having increased H₂ content relative the feed stream and a liquid stream having increased CO₂ content relative to the feed stream; (iii)expanding at least a portion of the liquid stream from step (ii); (iv)passing the expanded stream from step (iii) to a second vapour-liquid separator to produce a vapour stream having increased H₂ content relative the liquid stream from step (ii) and a liquid stream having increased CO₂ content relative to the liquid stream from step (ii); (v)expanding and heating a first portion of the liquid stream from step (iv); wherein cooling in step (i) is provided at least in part by heat exchange during heating of the first portion of the liquid stream from step (iv) in step (v).



Process and Apparatus for the Separation of Carbon Dioxide and Hydrogen

This invention relates to processes and apparatus for the low temperature separation of carbon dioxide and hydrogen.

The emission of carbon dioxide to the atmosphere from the combustion of fossil fuels is widely regarded as a significant contributor to global climate change. While a number of alternative “carbon-neutral” energy sources have been proposed, there are currently insufficient viable alternatives to the combustion of fossil fuels to meet global energy demands. There is therefore a need for technologies which are able to mitigate the environmental effects from the use of fossil fuels and from large-scale industrial processes such as steel and cement manufacture.

“Carbon dioxide Capture and Storage” (CCS) is a technology which has been proposed to reduce carbon dioxide emissions from a range of industrial sources, such as power generation and gas processing. CCS involves the capture of carbon dioxide at source, transportation of the carbon dioxide to an injection site and sequestration of the carbon dioxide for long-term storage in suitable geological formations, such as depleted oil and gas reservoirs and saline aquifers. In particular, captured carbon dioxide may be used in enhanced oil recovery techniques (EOR). One approach used in EOR involves the injection of gases into oil-bearing geological formations such that increased pressure of gas displaces oil deposits for recovery. Non-combustible gases are required for EOR purposes, since combustible gases (such as air) can cause the oil to ignite. Once the oil has been displaced from the reservoir, the carbon dioxide can be sequestered in the depleted reservoir for long-term storage. For sequestration purposes, a carbon dioxide purity of 95% or higher is likely to be of economic benefit to minimise compression power, the size of transportation systems, and storage volumes. The carbon dioxide is usually compressed to high pressure (typically around 10,000 to 20,000 kPa, for example 15,000 kPa) for transportation and storage [as used herein the unit kPa refers to absolute pressure unless stated otherwise]. Compression of CO₂ to such high pressures is an energy intensive process, and thus power consumption is a key consideration for any CCS model.

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A conventional technique for carbon capture is “post-combustion capture”. This involves the separation of carbon dioxide from flue gases prior to their emission to the atmosphere, and widely used techniques for post-combustion capture of carbon dioxide from power plants involve the use of amine scrubbers. Post-combustion capture technologies are an attractive solution in many cases since the necessary apparatus can readily be retrofitted at the effluent end of existing combustion apparatus.

A potential disadvantage of conventional post-combustion capture processes is that the concentration of carbon dioxide in the flue gas is relatively low (generally around 10 to 20% on a dry basis). Since extraction of carbon dioxide from streams containing high carbon dioxide content is easier than from those with lower carbon dioxide content and equipment is physically smaller due to the feed gas flow being relatively low, pre-combustion capture and oxy-fuel combustion processes have been proposed as alternatives to conventional post-combustion capture processes. Furthermore, the efficient use of geological formations for the capture of carbon dioxide requires that the carbon dioxide sent for storage should be substantially free of other components. In particular, purer carbon dioxide is required to meet the specifications for EOR. Alternative approaches to flue gas processing for the recovery of carbon dioxide from combustion processes can facilitate the use of process technology that produces purer carbon dioxide.

Pre-combustion capture involves the production of synthesis gas (comprising hydrogen, carbon monoxide, water and carbon dioxide) either by reforming of natural gas or by gasification of coal or biomass. Additional hydrogen can be recovered by a water-gas shift reaction with the carbon monoxide produced reacting with water to form carbon dioxide and hydrogen. Conditioned hydrogen may subsequently be burnt in a turbine, producing only water as a combustion by-product. Usually a combined cycle turbine is used in a process known as integrated gasification combined cycle (IGCC).

There is a need in the art for robust and effective methods for the separation of hydrogen from carbon dioxide in the context of the pre-combustion capture of carbon dioxide. In particular, processes are required which provide a carbon dioxide rich product stream at elevated pressure which is thus integrated with the existing compression requirements

for sequestration or EOR.

The present invention provides novel processes and apparatus for the separation of carbon dioxide and hydrogen gases. In preferred embodiments of the invention, novel heat integration techniques are used to improve the efficiency of the process and to minimise the power requirements for downstream compression.

In a first aspect, the present invention provides a separation process wherein CO₂ is separated from a gaseous feed stream comprising CO₂ and H₂, the process comprising the steps of:

- (i) cooling and partially condensing the gaseous feed stream;
 - (ii) passing the cooled and partially condensed feed stream from step (i) to a first vapour-liquid separator to produce a vapour stream having increased H₂ content relative the feed stream and a liquid stream having increased CO₂ content relative to the feed stream;
 - (iii) expanding at least a portion of the liquid stream from step (ii);
 - (iv) passing the expanded stream from step (iii) to a second vapour-liquid separator to produce a vapour stream having increased H₂ content relative the liquid stream from step (ii) and a liquid stream having increased CO₂ content relative to the liquid stream from step (ii);
 - (v) expanding and heating a first portion of the liquid stream from step (iv);
- wherein cooling in step (i) is provided at least in part by heat exchange during heating of the first portion of the liquid stream from step (iv) in step (v).

The gaseous feed stream is preferably supplied to step (i) of the process of the invention at a pressure in the range of from 2000 to 10,000 kPa, more preferably from 3000 to 9000 kPa, and still more preferably from 4000 to 8000 kPa, for example 5000 kPa, 6000 kPa or 7000 kPa. Generally, a gaseous feed stream to be separated according to the invention will be supplied at atmospheric pressure and will be compressed to a pressure in the range of from 1000 to 10,000 kPa to form the gaseous feed stream. For example, a multistage compression train may be used to form the gaseous feed stream.

The gaseous feed stream is preferably supplied to step (i) of the process of the invention at a temperature in the range of from 0 to 50 °C, more preferably 10 to 30 °C, for example 15 °C.

In step (i), the gaseous feed stream is preferably cooled to a temperature of from -30 to -55 °C, more preferably from -40 to -55 °C, still more preferably from -45 to -55 °C, and most preferably from -50 to -55 °C for example -51 °C, -52 °C, -53 °C, or -54 °C. It will be appreciated that carbon dioxide freezes at -56.6 °C and thus -55 °C is an effective lower limit for the operating temperature in the process of the invention.

Following expansion of the liquid stream from step (ii) in step (iii), the operating pressure of the second vapour-liquid separator is preferably in the range of from 1000 to 6000 kPa, more preferably 2000 to 5000 kPa, for example 3000 kPa or 4000 kPa. Due to the thermodynamic properties of the CO₂ rich liquid stream from step (ii), the operating temperature of the second vapour liquid separator is essentially the same as that of the first vapour-liquid separator. Thus, the operating temperature of the second vapour-liquid separator is preferably in the range of from -30 to -55 °C, more preferably from -40 to -55 °C, still more preferably from -45 to -55 °C, and most preferably from -50 to -55 °C, for example -51 °C, -52 °C, -53 °C, or -54 °C.

As noted above, at least a portion of the cooling duty in step (i) is provided by heat exchange with the first portion of the expanded liquid stream from step (iv). Expansion of the first portion of the liquid stream in step (iv) provides a reduced pressure stream which is evaporated in heat exchange with the gaseous feed stream. In this way, the cooling requirements in step (i) are integrated with the heating requirements in step (v).

Depending on the temperature and pressure of the first portion of the expanded liquid stream from step (iv), expansion in step (v) may lead to cooling of the stream by the Joule Thomson effect. This can potentially lead to freezing of the expanded stream. In some embodiments it is therefore desirable to heat the first portion of the liquid stream from step (iv) prior to expansion in step (v), such that evaporation of the expanded stream provides effective cooling of the gaseous feed stream, whilst freezing of the expanded stream is avoided. For example, the first portion of the liquid stream from step

(iv) may be heated to a temperature in the range of from -35 to -45 °C prior to expansion in step (v). Heating of the first portion of the liquid stream from step (iv) prior to expansion is preferably by heat exchange during cooling of the gaseous feed stream.

While such a process is beneficial for the energy efficiency of the separation process, it has the disadvantage that expansion of the first portion of the liquid stream from step (iv) provides a CO₂ product stream which is reduced in pressure. As discussed above, CCS applications usually require a CO₂ product at high pressure, and thus any expansion of the CO₂ rich liquid stream from step (iv) leads to an increase in the power requirements for downstream compression of the CO₂ product.

In preferred embodiments of the present invention, processes are provided in which the power requirements for downstream compression are minimised.

Thus, in a preferred embodiment, the first portion of the liquid stream from step (iv) preferably comprises 50 wt% or less, more preferably 45 wt% or less, and most preferably 40 wt% or less of the liquid stream from step (iv).

The first portion of the liquid stream from step (iv) preferably comprises 10 wt% or more, more preferably 15 wt% or more, and most preferably 20 wt% or more of the liquid stream from step (iv).

Following expansion in step (v), the first portion of the liquid stream from step (iv) will generally have a pressure in the range of from 200 to 2000 kPa, more preferably 300 to 1500 kPa, still more preferably 400 to 1200 kPa, still more preferably 500 to 1000 kPa, and most preferably 600 to 800 kPa.

Following heating in step (v), the first portion of the liquid stream from step (iv) will generally have a temperature approaching that of the gaseous feed stream, from instance in the range of from -10 to 40 °C, more preferably 0 to 30 °C, for instance 5 to 25 °C.

By expanding a first portion comprising 50 wt% or less of the liquid stream from step (iv) in step (v) the present invention provides the advantage that the cooling provided by expansion of the first portion of the liquid stream from step (iv) can be closely matched with the cooling requirements in step (i). In this way, unnecessary expansion of the remainder of the liquid stream from step (iv) can be avoided. By reducing the amount of the CO₂ product stream (i.e. the liquid stream from step (iv)) which is expanded in step (v), a surprising reduction is obtained in the power requirements for downstream compression of the CO₂ product, while still providing adequate cooling to the gaseous feed stream in step (i).

Following expansion and heating in step (v) the first portion of the liquid stream from step (iv) is preferably compressed by known procedures to form a compressed CO₂ product. The compressed CO₂ product is suitable for sequestration or for EOR applications.

It has further been found that still a further improvement in heat integration can be obtained by expansion of more than one portion of the liquid stream from step (iv). By expanding more than one portion of the liquid stream from step (iv) it is possible to obtain a still closer match between the expansion of the liquid stream from step (iv) and the necessary cooling duty in step (i).

Thus, in a preferred embodiment, the process of the invention further comprises the step of:

- (vi) expanding and heating a second portion of the liquid stream from step (iv); wherein further cooling in step (i) is provided by heat exchange during heating of the second portion of the liquid stream from step (iv) in step (v).

In this embodiment, there are at least two expanded streams which contribute to the cooling of the gaseous feed stream in step (i), namely the first portion of the liquid stream from step (iv) and the second portion of the liquid stream from step (iv). The degree of expansion and the flow rate of each of the first and second portions of the liquid stream from step (iv) may be controlled so as to closely match the cooling requirements in step (i).

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The second portion of the liquid stream from step (iv) preferably comprises 50 wt% or less, more preferably 45 wt% or less, and most preferably 40 wt% or less of the liquid stream from step (iv).

The second portion of the liquid stream from step (iv) preferably comprises 10 wt% or more, more preferably 15 wt% or more, and most preferably 20 wt% or more of the liquid stream from step (iv).

In accordance with this embodiment of the invention, it is preferable that the second portion of the liquid stream from step (iv) remains at a higher pressure following expansion in step (vi) than the first portion of the liquid stream from step (iv) following expansion in step (v).

Thus, following expansion in step (vi), the second portion of the liquid stream from step (iv) will generally have a pressure in the range of from 800 to 2500 kPa, more preferably from 800 to 2000 kPa, and most preferably from 1000 to 1500 kPa.

Following heating in step (vi), the second portion of the liquid stream from step (iv) will generally have a temperature approaching that of the gaseous feed stream, from instance in the range of from -10 to 40 °C, more preferably 0 to 30 °C, for instance 5 to 25 °C.

Cooling in step (i) is thus preferably provided by at least one low pressure (preferably 200 to 2000 kPa) stream comprising the expanded first portion of the liquid stream from step (iv) and at least one intermediate pressure (preferably 900 to 2000 kPa) stream comprising the expanded second portion of the liquid stream from step (iv).

As suggested above, by closely matching the contribution of the at least one low pressure expanded stream and the at least one intermediate pressure expanded stream to the cooling requirements in step (i), the amount of expansion of the liquid stream from step (iv) required to provide the necessary cooling duty in step (i) can be minimised, thus also minimising the power required for subsequent compression of the CO₂ product.

Following expansion and heating in step (vi) the second portion of the liquid stream from step (iv) is also preferably compressed by known procedures to form a compressed CO₂ product. The compressed CO₂ product is suitable for sequestration or for EOR applications.

Yet a further improvement in heat integration can be obtained by expansion of a third portion of the liquid stream from step (iv).

Thus, in a particularly preferred embodiment, the process of the invention further comprises the step of:

- (vii) expanding and heating a third portion of the liquid stream from step (iv);
wherein further cooling in step (i) is provided by heat exchange during heating of the third portion of the liquid stream from step (iv) in step (vii).

In this embodiment, there are at least three expanded streams which contribute to the cooling of the gaseous feed stream in step (i), namely the first, second and third portions of the liquid stream from step (iv). The degree of expansion and the flow rate of each of the first, second and third portions of the liquid stream from step (iv) may be controlled so as to still more closely match the cooling requirements in step (i).

In accordance with this embodiment of the invention, it is preferable that the third portion of the liquid stream from step (iv) remains at a higher pressure following expansion in step (vi) than both the first and second portions of the liquid stream from step (iv) following expansion in step (v) and step (vi), respectively.

Thus, following expansion in step (vii), the third portion of the liquid stream from step (iv) will generally have a pressure in the range of from 1000 to 3000 kPa, more preferably from 1200 to 2500 kPa, and most preferably from 1400 to 2200 kPa.

Following heating in step (vii), the third portion of the liquid stream from step (iv) will generally have a temperature approaching that of the gaseous feed stream, from instance in the range of from -10 to 40 °C, more preferably 0 to 30 °C, for instance 5 to 25 °C.

Since the third portion of the liquid stream from step (iv) has the highest pressure after expansion, and thus requires less recompression subsequently to meet product requirements, it is generally desirable for the flow rate of this stream to be maximised within the constraints of the cooling requirements for the feed stream provided by the first and second portions of the liquid stream from step (iv).

In preferred embodiments, the third portion of the liquid stream from step (iv) comprises the balance of the liquid stream from step (iv). Thus, the third portion of the liquid stream from step (iv) preferably comprises 20 wt% or more, more preferably 30 wt% or more, still more preferably 40 wt% or more, and most preferably 50 wt% or more of the liquid stream from step (iv).

In a preferred embodiment of the invention, cooling in step (i) is thus provided by a low pressure (preferably 200 to 2000 kPa) stream comprising the expanded first portion of the liquid stream from step (iv); an intermediate pressure (preferably 800 to 2500 kPa) stream comprising the expanded second portion of the liquid stream from step (iv); and a high pressure (preferably 1200 to 3000 kPa) stream comprising the expanded third portion of the liquid stream from step (iv);

As suggested above, by controlling the contributions of each of the low pressure expanded stream, the intermediate pressure expanded stream, and the high pressure expanded stream to the cooling requirements in step (i), the amount of expansion of the liquid stream from step (iv) required to provide the necessary cooling duty in step (i) can be precisely optimised, thus minimising the power required for subsequent compression of the CO₂ product.

Following expansion and heating in step (vi) the second portion of the liquid stream from step (iv) is also preferably compressed by known procedures to form a compressed CO₂ product. The compressed CO₂ product is suitable for sequestration or for EOR applications.

In preferred embodiments, the third portion of the liquid stream from step (iv) comprises the balance of the liquid stream from step (iv). However, in some embodiments of the

invention, there may be a remainder portion of the liquid stream from step (iv) which is not required to be expanded as part of the cooling duty required in step (i). Where present, the remainder portion of the liquid stream from step (iv) is passed to compression by known procedures to form a compressed CO₂ product, optionally following heat exchange with the gaseous feed stream. The compressed CO₂ product is suitable for sequestration or for EOR applications.

As discussed above, it may be desirable in some embodiments to heat one or both of the second and third portions of the liquid stream from step (iv) prior to expansion in steps (vi) and (vii), respectively. Heating of the second and/or third portion of the liquid stream from step (iv) prior to expansion is preferably by heat exchange during cooling of the gaseous feed stream in step (i). In this way, a further contribution is provided to the cooling duty required in step (i). In this way, a further contribution to the cooling of the gaseous feed stream in step (i) is provided.

It will be appreciated that many embodiments of the invention involve compression of more than one CO₂ rich stream to form a compressed CO₂ product. Compression of multiple CO₂ rich streams is preferably by way of a multi-stage compression train. A number of streams having different pressures may be introduced to the multistage compression train at a stage having the corresponding pressure. Thus, the expanded first portion of the liquid stream from step (iv) is preferably introduced to a low pressure stage of the multistage compression train; the expanded second portion of the liquid stream from step (iv), where present, is preferably introduced to an intermediate pressure stage of the multistage compression train; the expanded third portion of the liquid stream from step (iv), where present, is preferably introduced to a high pressure stage of the multistage compression train; and the remainder portion of the liquid stream from step (iv), where present, is preferably introduced to a highest pressure stage of the multistage compression train. In this way, the multiple portions of the liquid stream from step (iv) are recombined in the course of the compression step to provide a combined compressed CO₂ product stream. Further compression stages are preferably used to increase the pressure of the CO₂ product stream to the levels required for sequestration and/or EOR applications (i.e. from 10,000 to 20,000 kPa).

In some embodiments of the invention, it may be energy efficient to supplement the cooling duty provided by expansion of one or more portions of the liquid stream from step (iv) with an external mechanical refrigeration cycle. In this way, the need for expansion of the liquid stream from step (iv), and hence the power requirements for product gas compression, may be reduced.

The H₂ rich vapour stream from step (ii) is recovered from the first vapour liquid separator at low temperature, and the process of the invention preferably further comprises the step of:

- (viii) reheating the H₂ rich vapour stream from step (ii) downstream of the first vapour liquid separator.

Preferably, the H₂ rich vapour stream from step (ii) is reheated in heat exchange during cooling of the gaseous feed stream in step (i). In this way there is provided a further contribution to cooling of the feed gas stream, thus reducing the cooling duty borne by expansion of one or more portions of the liquid stream from step (iv). As noted above, this reduces the power requirements for compression of the CO₂ product. Generally, the H₂ rich vapour stream from step (ii) is reheated to a temperature approaching the temperature of the gaseous feed stream, for instance in the range of from 0 to 40 °C, more preferably from 10 to 30 °C, for example 15 to 20 °C.

The H₂ rich vapour stream from step (ii) will usually contain a recoverable quantity of CO₂, in some cases this may be from 10 to 30 mol% of the CO₂ content of the gaseous feed stream. Separation of residual CO₂ from the H₂ rich vapour stream from step (ii) is thus preferred in order to maximise the overall CO₂ recovery from the process.

Thus, in preferred embodiments of the invention, the process of the invention further comprises the step of:

- (ix) passing the reheated H₂ rich vapour stream from step (viii) to a secondary CO₂ separation process to obtain a H₂ rich gas stream.

The type of secondary CO₂ separation process used in step (ix) is not particularly limited, and known processes such as physical solvent absorption, chemical solvent absorption,

membrane separation or pressure swing adsorption (PSA) may be appropriate. In particular, physical solvent absorption processes may be preferred in many cases, since physical solvent absorption processes are well-suited to the high volume removal of CO₂ from gas streams, particularly where it is not necessary to obtain extremely low levels of residual CO₂ in the gaseous product. By the use of a secondary CO₂ separation process, the overall CO₂ recovery of the process may be increased to 90 mol% or greater of the CO₂ in the gaseous feed stream. Following the secondary CO₂ process, the recovered CO₂ may be passed to a compression step as described above. For instance, the CO₂ recovered in step (ix) is preferably passed to an appropriate stage of a multistage compression train whereupon it is recombined with the CO₂ rich streams obtained from step (iv).

The reheated H₂ rich vapour stream from step viii) is at a pressure which is generally above what is required for downstream combustion of H₂. Power can thus be recovered from this stream by work-expansion to the pressure required for H₂ fuel gas stream. Work expansion of the H₂ rich vapour stream from step (ii) may take place before secondary CO₂ removal in step (ix) or following secondary CO₂ removal. Generally, to avoid unwanted expansion of CO₂, work expansion preferably takes place following secondary CO₂ removal in step (ix). Thus, in a preferred embodiment, the process of the invention further comprises the step of:

- (x) work expanding at least a portion of the reheated H₂ rich vapour stream from step (viii) or at least a portion of the H₂ gas stream from step (ix).

Preferably work-expansion in step (x) uses a turbo-compressor linked to a power generator. Alternatively, work-expansion of the at least a portion of the reheated H₂ rich vapour stream from step (viii) or the at least a portion of the H₂ gas stream from step (ix) may be used to assist in boosting the pressure of the feed gas, e.g. by way of a turbo-expander having a compressor at the brake end.

Following expansion in step (x) a first H₂ fuel gas stream is obtained at a pressure typically suitable for downstream combustion processes.

The H₂ rich vapour stream from step (iv) is similarly recovered from the second vapour liquid separator at low temperature, and the process of the invention preferably further comprises the step of:

- (xi) reheating the H₂ rich vapour stream from step (iv) downstream of the second vapour liquid separator to provide a second H₂ fuel gas stream.

Preferably, the H₂ rich vapour stream from step (iv) is reheated in heat exchange during cooling of the gaseous feed stream in step (i). In this way there is provided still a further contribution to cooling of the feed gas stream, thus further reducing the cooling duty borne by expansion of one or more portions of the liquid stream from step (iv). Generally, the H₂ rich vapour stream from step (iv) is reheated to a temperature approaching the temperature of the gaseous feed stream.

Since the H₂ rich vapour stream from step (iv) contains only a minor proportion of the H₂ content of the gaseous feed stream, is already at reduced pressure, and contains negligible CO₂, further processing to recover CO₂ and/or work expansion of this stream is generally not required. The second H₂ fuel gas stream is preferably combined with the first H₂ fuel gas stream prior to use of the H₂ fuel gas streams in a downstream combustion process.

In a further preferred embodiment, the process of the invention further comprises the step of:

- (xii) passing the first H₂ fuel gas stream and/or the second H₂ fuel gas stream to a combustion process.

Preferably, the combustion process in step (xii) is used to drive a turbine to generate power.

The gaseous feed stream used in the process of the invention is preferably obtained by reforming of a hydrocarbon fuel, such as natural gas, or by gasification of a carbonaceous fuel, such as coal or biomass. An additional shift reaction with steam is preferably used to convert carbon monoxide from the reforming/gasification step to additional H₂ and CO₂.

The CO₂ and H₂ content of the gaseous feed stream depends on the carbonaceous or hydrocarbon fuel used in the reforming/gasification step. However, the CO₂ content of the gaseous feed stream is generally in the range of from 10 to 60%, and more preferably from 20 to 50 mol%. The H₂ content of the gaseous feed stream is generally in the range of from 40 to 90 mol%, and more preferably from 50 to 80 mol%.

In some embodiments, the gaseous feed stream may comprise minor amounts of carbon monoxide (preferably less than 2 mol%), as well as minor amounts of nitrogen (preferably less than 5 mol%) and argon (preferably less than 1 mol%).

Where natural gas is used to produce the gaseous feed stream, the gaseous feed stream may also comprise minor amounts of methane. However, the amount of methane in the gaseous feed stream is preferably as low as possible since any residual methane in the gaseous feed stream reduces the recovery of carbon (in the form of CO₂) from the process. Preferably, the amount of methane in the gaseous feed stream is less than 0.5 mol%, more preferably less than 0.1 mol%, still more preferably less than 0.05 mol%, and most preferably less than 0.02 mol%.

The gaseous feed stream is treated to remove water prior to step (i), since water is likely to freeze under the operating conditions of the process of the invention, and therefore disrupt the operation of the processing apparatus. Water removal is generally by known condensation processes, for example using a multistage compression train with vapour-liquid separators between compression stages to remove condensed water. In general a subsequent drying step over a dessicant, such as molecular sieves, is also used to minimise the water content of the gaseous feed stream. The water content of the gaseous feed stream is preferably less than 10 ppm by volume, more preferably less than 5 ppm by volume, still more preferably less than 2 ppm by volume, and most preferably less than 1 ppm by volume.

If necessary, the gaseous feed stream may also be treated prior to step (i) to remove sulphur containing substances (e.g. H₂S) and/or mercury.

It will be appreciated that the process of the invention as described above may comprise a number of heat exchange steps. The configuration of the heat exchange steps is not particularly limited and may involve separate heat exchangers for each separate heat exchange step, or where appropriate, a number of different heat exchange steps may be combined within a single multistream heat exchanger.

In another aspect, the present invention provides a separation apparatus for separating CO₂ from a gaseous feed stream comprising CO₂ and H₂, the apparatus comprising the following parts:

- (i) means for cooling and partially condensing the feed stream;
- (ii) first vapour-liquid separator adapted to separate the cooled and partially condensed feed stream from part (i) to produce a vapour stream having increased H₂ content relative the feed stream and a liquid stream having increased CO₂ content relative to the feed stream;
- (iii) means for expanding at least a portion of the liquid stream from part (ii);
- (iv) a second vapour-liquid separator adapted to separate the expanded stream from part (iii) to produce a vapour stream having increased H₂ content relative the liquid stream from part (ii) and a liquid stream having increased CO₂ content relative to the liquid stream from part (ii);
- (v) means for expanding and heating a first portion of the liquid stream from part (iv);

wherein the means for cooling in part (i) and the means for heating in part (v) comprises one or more heat exchangers adapted to pass the gaseous feed stream in heat exchange contact with the expanded first portion of the liquid stream from part (iv).

The first vapour liquid separator is preferably adapted to operate at a temperature in the range of from -30 to -55 °C, more preferably from -40 to -55 °C, still more preferably from -45 to -55 °C, and most preferably from -50 to -55 °C for example -51 °C, -52 °C, -53 °C, or -54 °C.

The first vapour liquid separator is preferably adapted to operate at pressure in the range of from 2000 to 10,000 kPa, more preferably 3000 to 9000 kPa, and still more preferably

from 4000 to 8000 kPa, for example 5000 kPa, 6000 kPa or 7000 kPa.

The second vapour-liquid separator is preferably also adapted to operate at a temperature in the range of from -30 to -55 °C, more preferably from -40 to -55 °C, still more preferably from -45 to -55 °C, and most preferably from -50 to -55 °C for example -51 °C, -52 °C, -53 °C, or -54 °C.

The second vapour liquid separator is preferably adapted to operate at a pressure in the range of from 1000 to 6000 kPa, more preferably 2000 to 5000 kPa, for example 3000 kPa or 4000 kPa.

The apparatus of the invention preferably further comprises means for compressing the expanded, heated first portion of the liquid stream from part (iv) following part (v) to form a compressed CO₂ product.

The means for expanding the first portion of the liquid stream from part (iv) in part (v) is preferably adapted to expand the first portion of the liquid stream from part (iv) to a pressure in the range of from 200 to 2000 kPa, more preferably 300 to 1500 kPa, still more preferably 400 to 1200 kPa, still more preferably 500 to 1000 kPa, and most preferably 600 to 800 kPa.

In some embodiments, the apparatus of the invention may comprise means for heating the first portion of the liquid stream from part (iv) prior to expansion in part (v). Preferably, the means for heating the first portion of the liquid stream from part (iv) prior to expansion in part (v) comprises one or more heat exchangers adapted to pass the first portion of the liquid stream from part (iv) in heat exchange contact with the gaseous feed stream, to supplement the cooling provided by part (i). In this way, the apparatus of the invention enables the evaporation of the liquid stream from part (iv) to provide effective cooling of the gaseous feed stream without freezing of the expanded stream due to Joule-Thomson cooling.

In a preferred embodiment, the apparatus of the invention further comprises:

- (vi) means for expanding and heating a second portion of the liquid stream

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from part (iv);

wherein the means for heating in part (vi) comprises one or more heat exchangers adapted to pass the gaseous feed stream in heat exchange contact with the expanded second portion of the liquid stream from part (iv).

In accordance with this embodiment, the apparatus of the invention provides at least two expanded streams to contribute to the cooling of the gaseous feed stream in part (i), namely the first portion of the liquid stream from part (iv) and the second portion of the liquid stream from part (iv). The apparatus of the invention comprises means for controlling the degree of expansion and the flow rate of each of the first and second portions of the liquid stream from part (iv) so as to closely match the cooling requirements in part (i).

Preferably, the means for expanding the second portion of the liquid stream from part (iv) in part (vi) is adapted to expand the second portion of the liquid stream from part (iv) to a pressure in the range of from 800 to 2500 kPa, more preferably 800 to 2000 kPa, and most preferably 1000 to 1500 kPa.

The apparatus of the invention preferably further comprises means for compressing the expanded, heated second portion of the liquid stream from part (iv) following part (vi) to form a compressed CO₂ product.

In a further preferred embodiment, the apparatus of the invention further comprises:

(vii) means for expanding and heating a third portion of the liquid stream from part (iv);

wherein the means for heating in part (vii) comprises one or more heat exchangers adapted to pass the gaseous feed stream in heat exchange contact with the expanded third portion of the liquid stream from part (iv).

In this embodiment, the apparatus of the invention provides at least three expanded streams to contribute to the cooling of the gaseous feed stream in part (i), namely the first, second and third portions of the liquid stream from part (iv). The apparatus of the invention comprises means for controlling the degree of expansion and the flow rate of

each of the first, second and third portions of the liquid stream from part (iv) so as to still more closely match the cooling requirements in part (i).

Preferably, the means for expanding the third portion of the liquid stream from part (iv) in part (vi) is adapted to expand the third portion of the liquid stream from part (iv) to a pressure in the range of from 1000 to 3000 kPa, more preferably 1200 to 2500 kPa, and most preferably 1400 to 2200 kPa.

The apparatus of the invention preferably further comprises means for compressing the expanded, heated third portion of the liquid stream from part (iv) following part (vii) to form a compressed CO₂ product.

Generally, the third portion of the liquid stream from part (iv) comprises the balance of the liquid stream from step (iv). However, in some embodiments, the apparatus of the invention may comprise means for compressing a remainder portion of the liquid stream from part (iv) to form a compressed CO₂ product. Optionally, the apparatus may further comprise means for passing the remainder portion of the liquid stream from step (iv) in heat exchange contact with the gaseous feed stream.

As discussed in connection with the first portion of the liquid stream from part (iv), the apparatus of the invention may comprise means for heating the second and/or third portions of the liquid stream from part (iv) prior to expansion in parts (vi) and (vii), respectively. Preferably, the means for heating the second and/or third portions of the liquid stream from part (iv) prior to expansion comprises one or more heat exchangers adapted to pass one or more of the first, second and third portions of the liquid stream from part (iv) in heat exchange contact with the gaseous feed stream, to supplement the cooling provided by part (i).

As noted above, the apparatus of the invention may comprise means for compressing more than one CO₂ rich stream to form a compressed CO₂ product. Preferably, the apparatus comprises a multi-stage compression train adapted to compress a number of streams having different pressures by introduction of streams at the stage of the multistage compression train having a corresponding pressure.

In some embodiments, the means for cooling and partially condensing the gaseous feed stream in part (i) may further comprise an external mechanical refrigeration cycle.

The apparatus of the invention may further comprise:

- (xiii) means for reheating the H₂ rich vapour stream from part (ii) downstream of the first vapour liquid separator.

Preferably, the means for reheating the H₂ rich vapour stream from part (ii) comprises one or more heat exchangers adapted to pass the H₂ rich vapour stream from part (ii) in heat exchange contact with the gaseous feed stream, to supplement the cooling provided by part (i).

In order to maximise the CO₂ recovery obtainable using the apparatus of the invention, the apparatus preferably further comprises:

- (xiv) a secondary CO₂ separation apparatus adapted to separate CO₂ from the H₂ rich vapour stream from part (viii) to provide a H₂ rich gas stream.

As discussed above, the type of secondary CO₂ separation apparatus used in part (ix) is not particularly limited, and known apparatus for physical solvent absorption, chemical solvent absorption, membrane separation or pressure swing absorption (PSA) may be used.

Preferably the apparatus of the invention further comprises means for compressing separated CO₂ from part (ix) to provide a compressed CO₂ product. Most preferably, the means for compressing separated CO₂ from part (ix) comprises a multistage compression train as described above.

As discussed above, power can be recovered from the reheated H₂ rich vapour stream from part (viii). Thus, the apparatus of the invention may comprise:

- (xv) means for work expanding at least a portion of the reheated H₂ rich vapour stream from part (viii) or at least a portion of the H₂ gas stream from part (ix).

The means for work-expanding at least a portion of the heated H₂ rich vapour stream from part (viii) or at least a portion of the H₂ gas stream from part (ix) preferably comprises one or more turbo-expanders. The brake end of the turbo-expander may comprise means for generating electricity. Alternatively, the brake end of the turbo-expander may comprise a compressor adapted to provide compression for the gaseous feed stream. Generally, to avoid unwanted expansion of CO₂, the apparatus comprises means for work expanding at least a portion of the H₂ gas stream from part (ix).

The apparatus of the invention may further comprise:

- (xvi) means for reheating the H₂ rich vapour stream from part (iv) downstream of the second vapour liquid separator to provide a second H₂ fuel gas stream.

Preferably, the means for reheating the H₂ rich vapour stream from part (iv) comprises one or more heat exchangers adapted to pass the H₂ rich vapour stream from part (iv) in heat exchange contact with the gaseous feed stream, to supplement the cooling provided by part (i).

The apparatus of the invention may further comprise:

- (xvii) a power generation apparatus wherein power is generated by combustion of the first H₂ fuel gas stream and/or the second H₂ fuel gas stream.

As discussed above, the apparatus of the invention may comprise a number of heat exchangers. The configuration of the heat exchangers is not particularly limited and may involve separate heat exchangers for each separate heat exchange step, or where appropriate, a number of different heat exchange steps may be combined within a single multistream heat exchanger.

The invention will now be described in greater detail with reference to preferred embodiments and with the aid of the accompanying figures, in which:

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Figure 1 shows an embodiment of a separation process and apparatus according to the present invention.

Figure 2 shows a schematic arrangement of an integrated gasification and carbon capture power generation process and apparatus comprising a separation process and apparatus according to the present invention.

In the embodiment of the invention shown in Figure 1, a gaseous feed stream comprising H_2 and CO_2 (100) is passed to a feed gas compression train (110). For clarity, only one stage of the compression train is shown. Each compression stage comprises a compressor (120), cooler (130) (typically air or water cooled), and a vapour liquid separator (140) to remove a condensed liquid (150), which comprises substantially water.

The compressed feed stream (200) is passed to a pre-treatment unit (250), including a molecular sieve dehydration unit to avoid freezing of water in the downstream unit and mercury removal, if necessary, to protect any aluminium equipment. The dry feed gas (300) is routed to a high efficiency, multi-stream heat exchanger (310) where it is cooled and partially condensed against returning product streams.

The cooled two phase stream (315) is passed to a vapour-liquid separator (320) to give a CO_2 rich liquid stream (325) and a hydrogen rich vapour stream (425). The hydrogen rich vapour stream (425) is routed back through the heat exchanger (310) at essentially feed gas pressure and is heated close to the feed gas temperature. The reheated stream (430) has residual CO_2 content and further processing of this stream in a secondary recovery unit (435) will maximise the recovery of CO_2 . The CO_2 stream (440) obtained from the secondary recovery unit (435) is preferably passed to a multi-stage compression train (415) where it is combined with other CO_2 streams (365, 385, 410), and compressed and cooled in stages to provide a CO_2 product stream (420) meeting transportation and/or storage requirements.

The hydrogen rich stream (445) obtained from the secondary recovery unit (435) is heated (450) and the heated stream (455) is passed to a turbo-expander (460) in order

to recover power.

The CO₂ rich liquid (325) produced in the primary high pressure separator is flashed across a valve (330). The resultant two phase stream (335) is separated in a vapour-liquid separator (340) to give a CO₂ rich liquid stream (345) and a further hydrogen rich vapour stream (465), which is routed back through the heat exchanger (310) at intermediate pressure. The resulting reheated stream (470) is combined with the main hydrogen fuel gas stream downstream of the turbo expander (460) to provide a hydrogen product stream (480).

The CO₂ rich liquid stream (345) from the secondary vapour-liquid separator (340) is used to provide cooling to gaseous feed stream through evaporation of reduced pressure streams at a number of pressure levels in the heat exchanger (310). For the presented case, three different pressure levels are used: streams (350) and (370) are flashed to intermediate pressures across valves (355) and (375) respectively and the resultant reduced pressure streams (360) and (380) are evaporated and warmed against the feed stream in exchanger (310). The remaining fraction of the liquid stream (390) is warmed to an intermediate temperature in the heat exchanger (310) and the intermediate temperature stream (395) is flashed to a low pressure and reduced temperature across a valve (400). The resulting stream (405) is then evaporated and warmed in the heat exchanger (310).

The CO₂ rich product streams (365, 385, 410) are combined at appropriate points within the multi-stage compression train (415), preferably together with the recovered CO₂ stream (440) from the recovery unit (435), and compressed to form a CO₂ product stream (420) meeting transportation and storage requirements. Inter- and after-cooling duties within the compressor train are typically provided by air or water.

In the integrated gasification and carbon capture process shown schematically in Figure 2, a hydrocarbon or carbonaceous fuel (500) is passed to a gasification/reforming stage (510), which is supplied by an air separation unit (520). Following cooling (530) and particulate removal (540), the reformat gas is passed to a shift reaction stage (550) to convert carbon monoxide to CO₂. Subsequent cooling (560) and sulphur dioxide

removal (570) stages provide a feed gas comprising H_2 and CO_2 which is suitable for separation according to the process of the invention. If required, sulphur may be recovered from the separated H_2S in a sulphur recovery stage (580).

The feed gas is passed to a compression and dehydration stage (590), with further removal of water and optionally mercury in a pretreatment stage (610). The resulting gaseous feed stream is passed to separation process/apparatus (610) according to the invention (e.g. as shown in Figure 1), comprising a cryogenic separation stage (620).

A secondary CO_2 recovery stage (630) is used to recover residual CO_2 from the hydrogen rich vapour stream, and an expansion stage (640) is used to recover power from the resulting H_2 rich gas. The H_2 rich gas may be passed to a combustion stage (650) to drive a power generation turbine system. Combined carbon dioxide streams are passed to a CO_2 compression stage (660) and subsequently to transportation and storage for subsequent sequestration or EOR use (670).

Example

Table 1 shows typical operating parameters for the process of the invention shown in Figure 1 when used to separate a gaseous mixture consisting of approximately 55.8 mol% hydrogen, 37.9 mol% CO₂, 1.7 mol% CO, 3.9 mol% nitrogen, 0.6 mol% argon, 0.1 mol% water and trace amounts of methane. Overall CO₂ recovery is 93.7 mol% with a purity of 98.2%. Hydrogen recovery is in excess of 99.5 mol%.

Table 1

Stream Number	100	200	300	315	325
Temperature (°C)	35.0	30.0	30.0	-52.0	-52.0
Pressure (kPa(a))	3,200	7,050	7,000	6,990	6,980
Mass Flow (kg/h)	707,300	707,300	706,400	706,400	463,500
Vapour Fraction (wt)	1.0000	1.0000	1.0000	0.3437	0.0000
Vapour Phase mol. wt.	19.6	19.6	19.6	9.6	9.6
Liquid phase density (kg/m ³)	n/a	n/a	n/a	1147	1147
Molar Flow:					
H ₂ (kgmol/h)	20,077.4	20,077.4	20,077.4	20,077.4	98.5
CO ₂ (kgmol/h)	13,649.2	13,649.2	13,649.2	13,649.2	10,456.5
CO (kgmol/h)	600.8	600.8	600.8	600.8	31.0
Nitrogen (kgmol/h)	1,393.5	1,393.5	1,393.5	1,393.5	53.5
Argon (kgmol/h)	231.6	231.6	231.6	231.6	19.1
Methane (kgmol/h)	7.2	7.2	7.2	7.2	0.7
H ₂ O (kgmol/h)	50.7	50.7	0	50.7	0
Total (kgmol/h)	36,010	36,010	35,960	35,960	10,660

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Stream Number	335	345	350	360	365
Temperature (°C)	-51.4	-51.4	-51.4	-52.2	21.1
Pressure (kPa(a))	3,010	3,000	3,000	1,150	1,140
Mass Flow (kg/h)	463,500	461,700	152,600	152,600	152,600
Vapour Fraction (wt)	0.0039	0.0000	0.0000	0.0101	1.0000
Vapour Phase mol. wt.	16.8	16.8	16.8	32.3	43.8
Liquid phase density (kg/m ³)	1148	1148	1148	1155	n/a
Molar Flow:					
H ₂ (kgmol/h)	98.5	33.7	11.1	11.1	11.1
CO ₂ (kgmol/h)	10,456.5	10,428.7	3,446.3	3,446.3	3,446.3
CO (kgmol/h)	31.0	26.6	8.8	8.8	8.8
Nitrogen (kgmol/h)	53.5	43.5	14.4	14.4	14.4
Argon (kgmol/h)	19.1	17.3	5.7	5.7	5.7
Methane (kgmol/h)	0.7	0.6	0.2	0.2	0.2
H ₂ O (kgmol/h)	0	0	0	0	0
Total (kgmol/h)	10,660	10,550	3,486	3,486	3,486

Stream Number	370	380	385	390	395
Temperature (°C)	-51.4	-51.4	21.1	-51.4	-44.8
Pressure (kPa(a))	3,000	1,700	1,690	3,000	2,990
Mass Flow (kg/h)	182,700	182,700	182,700	126,400	126,400
Vapour Fraction (wt)	0.0000	0.0032	1.0000	0.0000	0.0000
Vapour Phase mol. wt.	16.8	25.4	43.8	16.8	
Liquid phase density (kg/m ³)	1148	1150	n/a	1148	1124
Molar Flow:					
H ₂ (kgmol/h)	13.3	13.3	13.3	9.2	9.2
CO ₂ (kgmol/h)	4,126.9	4,126.9	4,126.9	2,855.5	2,855.5
CO (kgmol/h)	10.5	10.5	10.5	7.3	7.3
Nitrogen (kgmol/h)	17.2	17.2	17.2	11.9	11.9
Argon (kgmol/h)	6.8	6.8	6.8	4.7	4.7
Methane (kgmol/h)	0.2	0.2	0.2	0.0	0.0
H ₂ O (kgmol/h)	0	0	0	0	0
Total (kgmol/h)	4,175	4,175	4,175	2,889	2,889

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Stream Number	405	410	420	425	430
Temperature (°C)	-55.0	21.1	45.0	-52.0	21.1
Pressure (kPa(a))	650	640	15,000	6,980	6,970
Mass Flow (kg/h)	126,400	126,400	567,100	242,900	242,900
Vapour Fraction (wt)	0.0686	1.0000	0.0000	1.0000	1.0000
Vapour Phase mol. wt.	40.9	43.8		9.6	9.6
Liquid phase density (kg/m ³)	1168	n/a	670.8	1147	
Molar Flow:					
H ₂ (kgmol/h)	9.2	9.2	92.0	19,978.9	19,978.9
CO ₂ (kgmol/h)	2,855.5	2,855.5	12,785.1	3,192.7	3,192.7
CO (kgmol/h)	7.3	7.3	43.5	569.8	569.8
Nitrogen (kgmol/h)	11.9	11.9	67.4	1,340.0	1,340.0
Argon (kgmol/h)	4.7	4.7	28.0	212.6	212.6
Methane (kgmol/h)	0.0	0.0	1.4	6.6	6.6
H ₂ O (kgmol/h)	0	0	0	0	0
Total (kgmol/h)	2,889	2,889	13,020	25,300	25,300

Stream Number	445	455	465	470	480
Temperature (°C)	31.8	1000.0	-51.4	21.1	32.2
Pressure (kPa(a))	6,940	6,920	3,000	2,990	2,990
Mass Flow (kg/h)	137,500	137,500	1,828	1,828	139,300
Vapour Fraction (wt)	1.0000	1.0000	1.0000	1.0000	1.0000
Vapour Phase mol. wt.	6.0	6.0	16.8	16.8	6.1
Liquid phase density (kg/m ³)			1148		
Molar Flow:					
H ₂ (kgmol/h)	19,920.6	19,920.6	64.8	64.8	19,985.4
CO ₂ (kgmol/h)	836.1	836.1	27.8	27.8	863.9
CO (kgmol/h)	552.9	552.9	4.4	4.4	557.3
Nitrogen (kgmol/h)	1,316.2	1,316.2	9.9	9.9	1,326.1
Argon (kgmol/h)	201.9	201.9	1.8	1.8	203.6
Methane (kgmol/h)	5.7	5.7	0.1	0.1	5.8
H ₂ O (kgmol/h)	0	0	0	0	0
Total (kgmol/h)	22,830	22,830	109	109	22,940

Claims

1. A separation process wherein CO₂ is separated from a gaseous feed stream comprising CO₂ and H₂, the process comprising the steps of:
 - (i) cooling and partially condensing the feed stream;
 - (ii) passing the cooled and partially condensed feed stream from step (i) to a first vapour-liquid separator to produce a vapour stream having increased H₂ content relative the feed stream and a liquid stream having increased CO₂ content relative to the feed stream;
 - (iii) expanding at least a portion of the liquid stream from step (ii);
 - (iv) passing the expanded stream from step (iii) to a second vapour-liquid separator to produce a vapour stream having increased H₂ content relative the liquid stream from step (ii) and a liquid stream having increased CO₂ content relative to the liquid stream from step (ii);
 - (v) expanding and heating a first portion of the liquid stream from step (iv);wherein cooling in step (i) is provided at least in part by heat exchange during heating of the first portion of the liquid stream from step (iv) in step (v).
2. A separation process according to Claim 1, wherein the gaseous feed stream is supplied to step (i) at a pressure in the range of from 2000 to 10,000 kPa.
3. A separation process according to Claim 1 or Claim 2, wherein the gaseous feed stream is supplied to step (i) at a temperature in the range of from 0 to 50 °C.
4. A separation process according to any one of the preceding claims, wherein the gaseous feed stream is cooled in step (i) to a temperature of from -30 to -55 °C.
5. A separation process according to any one of the preceding claims, wherein the operating pressure of the second vapour-liquid separator is in the range of from 1000 to 6000 kPa.

6. A separation process according to any one of the preceding claims, wherein the operating temperature of the second vapour liquid separator is in the range of from -30 to -55 °C.
7. A process according to any one of the preceding claims, wherein the first portion of the liquid stream from step (iv) is compressed following expansion and heating in step (v) to form a compressed CO₂ product.
8. A process according to any one of the preceding claims, further comprising the step of:
(vi) expanding and heating a second portion of the liquid stream from step (iv); wherein further cooling in step (i) is provided by heat exchange during heating of the second portion of the liquid stream from step (iv) in step (v).
9. A process according to Claim 8, wherein the second portion of the liquid stream from step (iv) is at a higher pressure following expansion in step (vi) than the first portion of the liquid stream from step (iv) following expansion in step (v).
10. A process according to Claim 8 or Claim 9, wherein the second portion of the liquid stream from step (iv) is compressed following expansion and heating in step (vi) to form a compressed CO₂ product.
11. A process according to any one of Claims 8 to 10, further comprising the step of:
(vii) expanding and heating a third portion of the liquid stream from step (iv); wherein further cooling in step (i) is provided by heat exchange during heating of the third portion of the liquid stream from step (iv) in step (vii).
12. A process according to Claim 11, wherein the third portion of the liquid stream from step (iv) is at a higher pressure following expansion in step (vi) than the first portion of the liquid stream from step (iv) following expansion in step (v) and/or the second portion of the liquid stream from step (iv) following expansion in step (vi).

13. A process according to any one of Claims 10 to 12, wherein the third portion of the liquid stream from step (iv) is compressed following expansion and heating in step (vii) to form a compressed CO₂ product.
14. A process according to any one of the preceding claims, wherein the first portion of the liquid stream from step (iv) is heated prior to expansion in step (v).
15. A process according to Claim 14, wherein the first portion of the liquid stream from step (iv) is heated prior to expansion in step (v) by heat exchange during cooling of the gaseous feed stream in step (i).
16. A process according to any one of the preceding claims, wherein further cooling in step (i) is provided by an external mechanical refrigeration cycle.
17. A process according to any one of the preceding claims, further comprising the step of:
(viii) reheating the H₂ rich vapour stream from step (ii) downstream of the first vapour liquid separator.
18. A process according to Claim 17, wherein the H₂ rich vapour stream from step (ii) is reheated in heat exchange during cooling of the gaseous feed stream in step (i).
19. A process according to Claim 17 or Claim 18, further comprising the step of:
(ix) passing the reheated H₂ rich vapour stream from step (viii) to a secondary CO₂ separation process to obtain a H₂ rich gas stream.
20. A process according to Claim 19, wherein the secondary CO₂ separation process comprises a physical solvent absorption process.
21. A process according to Claim 19 or Claim 20, wherein CO₂ recovered from the secondary CO₂ separation process is compressed to form a compressed CO₂ product.

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22. A process according to any one of the preceding claims, further comprising the step of:
- (x) work expanding at least a portion of the reheated H₂ rich vapour stream from step (viii) or at least a portion of the H₂ gas stream from step (ix) to provide a first H₂ fuel gas stream.
23. A process according to any one of the preceding claims, further comprising the step of:
- (xi) reheating the H₂ rich vapour stream from step (iv) downstream of the second vapour liquid separator to provide a second H₂ fuel gas stream.
24. A process according to Claim 23, wherein the H₂ rich vapour stream from step (iv) is reheated in heat exchange during cooling of the gaseous feed stream in step (i).
25. A process according to any one of Claims 22 to 24, further comprising the step of:
- (xii) passing the first H₂ fuel gas stream and/or the second H₂ fuel gas stream to a combustion process.
26. A process according to Claim 25, wherein the combustion process is used to drive a turbine to generate power.
27. A process according to any one of the preceding claims, wherein the gaseous feed stream is obtained by reforming of a hydrocarbon fuel or by gasification of a carbonaceous fuel.
28. A process according to Claim 27, wherein a shift reaction is used to convert carbon monoxide from the reforming/gasification step to additional H₂ and CO₂.
29. A separation apparatus for separating CO₂ from a gaseous feed stream comprising CO₂ and H₂, the apparatus comprising the following parts:
- (i) means for cooling and partially condensing the feed stream;

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- (ii) first vapour-liquid separator adapted to separate the cooled and partially condensed feed stream from part (i) to produce a vapour stream having increased H_2 content relative the feed stream and a liquid stream having increased CO_2 content relative to the feed stream;
- (iii) means for expanding at least a portion of the liquid stream from part (ii);
- (iv) a second vapour-liquid separator adapted to separate the expanded stream from part (iii) to produce a vapour stream having increased H_2 content relative the liquid stream from part (ii) and a liquid stream having increased CO_2 content relative to the liquid stream from part (ii);
- (v) means for expanding and heating a first portion of the liquid stream from part (iv);

wherein the means for cooling in part (i) and the means for heating in part (v) comprises one or more heat exchangers adapted to pass the gaseous feed stream in heat exchange contact with the expanded first portion of the liquid stream from part (iv).

- 30. An apparatus according to Claim 29, further comprising means for compressing the expanded, heated first portion of the liquid stream from part (iv) following part (v) to form a compressed CO_2 product.
- 31. An apparatus according to Claim 29 or Claim 30, further comprising:
 - (vi) means for expanding and heating a second portion of the liquid stream from part (iv);wherein the means for heating in part (vi) comprises one or more heat exchangers adapted to pass the gaseous feed stream in heat exchange contact with the expanded second portion of the liquid stream from part (iv).
- 32. An apparatus according to Claim 31, further comprising means for compressing the expanded, heated second portion of the liquid stream from part (iv) following part (vi) to form a compressed CO_2 product.

33. An apparatus according to any one of Claims 29 to 32, further comprising:
(vii) means for expanding and heating a third portion of the liquid stream from part (iv);
wherein the means for heating in part (vii) comprises one or more heat exchangers adapted to pass the gaseous feed stream in heat exchange contact with the expanded third portion of the liquid stream from part (iv).
34. An apparatus according to Claim 33, further comprising means for compressing the expanded, heated third portion of the liquid stream from part (iv) following part (vii) to form a compressed CO₂ product.
35. An apparatus according to any one of Claims 29 to 34, further comprising means for heating the first portion of the liquid stream from part (iv) prior to expansion in parts (v).
36. An apparatus according to Claim 35, wherein the means for heating the first portion of the liquid stream from part (iv) comprises one or more heat exchangers adapted to pass one the first portion of the liquid stream from part (iv) in heat exchange contact with the gaseous feed stream.
37. An apparatus according to any one of Claims 29 to 36, wherein the means for cooling and partially condensing the gaseous feed stream in part (i) further comprises an external mechanical refrigeration cycle.
38. An apparatus according to any one of Claims 29 to 37, further comprising:
(viii) means for reheating the H₂ rich vapour stream from part (ii) downstream of the first vapour liquid separator.
39. An apparatus according to Claim 38, wherein the means for reheating the H₂ rich vapour stream from part (ii) comprises one or more heat exchangers adapted to pass the H₂ rich vapour stream from part (ii) in heat exchange contact with the gaseous feed stream.

40. An apparatus according to any one of Claims 29 to 39, further comprising:
 - (ix) a secondary CO₂ separation apparatus adapted to separate CO₂ from the H₂ rich vapour stream from part (viii) to provide a H₂ rich gas stream.
41. An apparatus according to Claim 40, wherein the secondary CO₂ separation apparatus comprises a physical solvent absorption apparatus.
42. An apparatus according to Claim 40 or Claim 41, further comprising means for compressing CO₂ separated using the secondary CO₂ separation apparatus.
43. An apparatus according to any one of Claims 40 to 42, further comprising:
 - (viii) means for work expanding at least a portion of the H₂ gas stream from part (ix) to provide a first H₂ fuel gas stream.
44. An apparatus according to Claim 43, wherein the means for work expanding at least a portion of the H₂ gas stream from part (ix) comprises one or more turbo-expanders.
45. An apparatus according to any one of Claims 29 to 44, further comprising:
 - (ix) means for reheating the H₂ rich vapour stream from part (iv) downstream of the second vapour liquid separator to provide a second H₂ fuel gas stream.
46. An apparatus according to Claim 45, wherein the means for means for reheating the H₂ rich vapour stream from part (iv) comprises one or more heat exchangers adapted to pass the H₂ rich vapour stream from part (iv) in heat exchange contact with the gaseous feed stream.
47. An apparatus according to Claim 43 or Claim 46, further comprising:
 - (x) a power generation facility wherein power is generated by combustion of the first H₂ fuel gas stream and/or the second H₂ fuel gas stream.

Figure 1

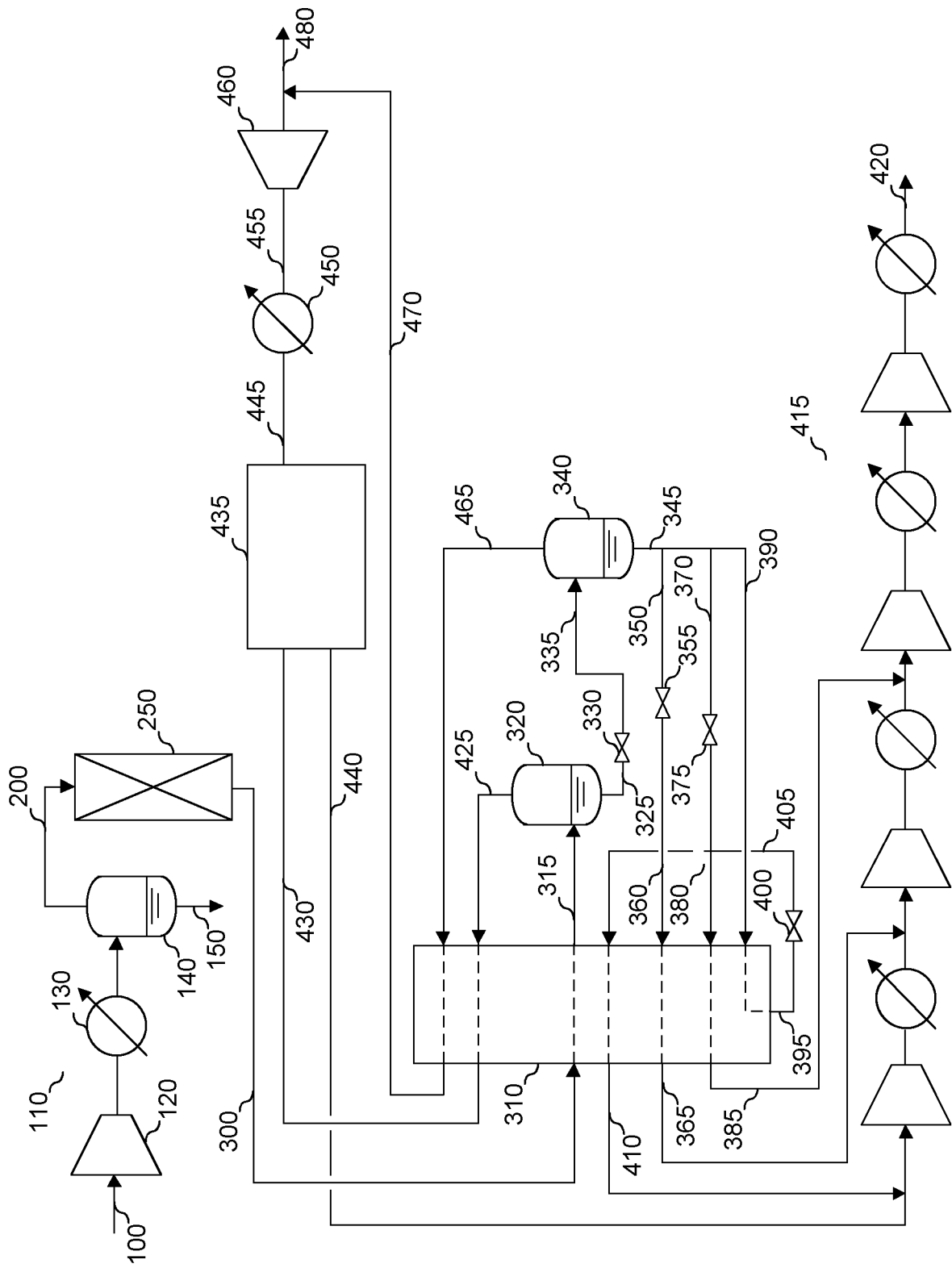


Figure 2

