The present invention relates to an energy efficient process for removing and sequestering CO₂ from energy process plants exhaust gas by chemical absorption and desorption respectively, where said exhaust gas is fed to an absorber containing a chemical absorbent where the CO₂ is absorbed in said absorbent and a CO₂-depleted exhaust gas stream is formed, and the CO₂ rich absorbent is further fed to a desorber where CO₂ is removed from the absorbent, and the absorbent essentially free of CO₂ is recirculated to the absorber and the desorbed CO₂ gas is discharged off, where said discharged CO₂ gas stream is compressed and the hot compressed stream is used directly to reboil the desorber or used to raise steam from boiler feed water which can be used as heat medium in a reboiler in said desorber.
"An energy efficient process for removing and sequestering CO₂ from energy process plants exhaust gas"

The present invention relates to an energy efficient process for removing and sequestering CO₂ from energy process plants exhaust gas.

When using gas turbines for converting thermal energy into mechanical energy, it is common to produce steam from the waste heat and use this steam to drive a steam turbine thus increasing the overall energy efficiency. Adding steam raising and a steam turbine to a gas turbine energy conversion process today involves very bulky process equipment. The boiler in particular is voluminous. The piping is also very substantial and complex. In an offshore environment as on an oil/gas platform it is therefore normal practice to install the gas turbine without any device for energy recovery from the exhaust gas since gas is cheap in such an environment while the space is at a minimum.

With the increasing focus on carbon induced global warming and introduction of carbon dioxide or energy taxes, this situation is being reevaluated. Increasing the energy efficiency of the process means that less climate gases are emitted. There is also focus on the possibility of sequestering carbon dioxide from the flue gases from such energy conversion plants.

Carbon dioxide recovery demands that the temperature of the exhaust gas is reduced to lower levels than the typical gas turbine exhaust gas temperature of 500 °C. Highest temperature allowable for separating carbon dioxide from gas with today's technology is in the region of 100-150 °C, but more typical for exhaust gas treatment would be 20-50 °C.

When treating the exhaust gas with liquid based methods (e.g. absorption), droplets will usually become present in the gas phase. Droplets may also arise
when condensation occurs. Thus it is desirable to remove such droplets either to recover the liquid or to avoid an extra effluent to the atmosphere.

A conventional design for a plant to achieve heat recovery, cooling, and carbon dioxide removal from exhaust gas will embrace a separate boiler, followed by a cooler for the gas before the carbon dioxide is removed in an absorption column with a demister unit downstream, and probably a blower to overcome the ensuing pressure drop. These process units are bulky and require instrumentation and control, in addition to a complex piping system to connect the various units.

It is known from the literature (e.g. Sawyer's Gas Turbine Engineering Handbook, 3rd ed., vol. II, chapters 7 and 14) how the energy recovery problems in gas turbine cycles may be solved technically, but the known solutions are costly in general, and too bulky for applying offshore. Furthermore, these technical solutions are associated with finite pressure drops that will lead to higher gas turbine exit pressure with reduced energy efficiency as a result. Alternatively some kind of blower can be installed to overcome the pressure drop.

It is further known from the literature (e.g. W.W. Bathie, Fundamentals of Gas Turbines, 2nd ed., Wiley, 1996, chapter 8) that gas turbine blades are cooled by internal water flow. The technique as it stands is designed to keep the blade surfaces cool enough to avoid material failure, and is not suitable for efficient heat transfer or energy recovery.

Also known from the literature (e.g. Kohl and Nielsen, Gas Purification, 5th ed., Gulf Publishing, 1997) is how carbon dioxide may be removed from gas by various means. Removal of carbon dioxide from flue gas represents a special problem due to lack of available pressure and the presence of contaminants like nitrogen oxides and oxygen in the gas. One such application is described in the
literature (Pauley et al., Oil & Gas Journal, May 14, 1984, p84-92). Many
developments to improve such technology have in recent years been invested
in (see e.g. Greenhouse Gas Control Technologies, edited by Eliasson, Riemer
and Wokaun, Pergamon, 1999).

The main objective of the present invention was to arrive at a more energy
efficient process for removing and sequestering CO₂ from energy process
plants exhaust gas.

The inventors found that an energy efficient process is achieved when the
discharged CO₂ and steam containing gas stream is compressed and the (hot)
compressed stream is used directly to provide reboiling for the desorber or used
to raise steam from boiler feed water which can be used as heat medium in a
reboiler for said desorber.

The present invention relates to how desorption of CO₂ can be done with
reduced energy consumption relative to the state of the art. It is observed that
the overhead stream from the desorber contains a large amount of water
vapour that is subsequently condensed to recover the water, and the latent heat
in this vapour is in known processes wasted in the condensation step. When, in
the conventional process as illustrated in Figure 1, CO₂ is recovered for the
purpose of carbon sequestration, the CO₂ in the desorber overhead stream has
to be compressed before it can be deposited in whatever way that is available
to the plant, but the application of a condenser to remove the bulk of the water
is practised in conventional plants. In the new method the overhead stream is
compressed without prior treatment to alter its temperature or condense water.
Vapour recompression as such is not normally profitable, but in this case the
compression step is combined with the compression of the CO₂ that is needed
anyway, and the compressor is now an extension in capacity of a machine that
is already required. The compressed gas mixture can be used directly to
provide heat for the reboiler in the desorption plant or it can be used to raise
steam from BFW (boiler feed water), and this steam can subsequently be used
as heat medium in the reboiler. It is obvious that the heat thus recovered could also be used for other heating purposes if present on site. And in the case of practicing the invention in the form where steam is raised, then the raised steam could be incorporated in local steam nets if desirable. Since the temperature in compressor outlet streams should be limited, more than one compression stage is foreseen. Heating or evaporating of BFW between stages is foreseen. Further, as water in the process stream condenses in this process it is separated from the gas phase in appropriate vessels. The liquid water is recovered and used to conserve the absorption process' water balance.

The invention will be further explained and envisaged in the following figures and examples.

**Figure 1** shows a flowsheet of an embodiment of a conventional desorption process.

**Figure 2** shows a flowsheet of an embodiment of the process according to the present invention.

**Figure 3** shows a flowsheet of another embodiment of the process according to the present invention.

The process can be further described by reference to **Figure 1** that shows the standard process. A simple modification on the standard process is to recover heat from stream 101 in the conventional process by heat exchange with stream 117. This will give improved pre-heating of the liquid entering the top of the desorption column and reduce the need for reboil at the bottom thus saving energy. This feature does not make sense, however, when overhead steam and CO$_2$ compression is practiced.
One embodiment of the present invention is shown in Figure 2. Here the desorption column (desorber) overhead stream 1 is compressed 53 with the compressed stream 2 being cooled by boiler feed water (BFW) 20 in heat exchanger 54 before the cooled overhead stream 3 is further compressed 55 rendering a hot stream 4 that is used to partially evaporate the heated BFW 22 in heat exchanger 56 thus partially condensing the overhead stream that as stream 5 enters the separator 57 where essentially condensed water leaves the bottom as stream 12 that is let down in pressure by valve 66 before it is mixed with stream 15 to be explained below and the mixed stream 13 is returned to the desorber 51 preferably mixed with stream 40 the rich amine stream to be stripped thus aiding pre-flashing of its CO₂ content. The moist CO₂ stream 6 leaving the top of the separator 57 is compressed 58 giving a hot stream 7 that is producing more steam in stream 21 that left the heat exchanger 59. The mainly CO₂ stream with condensed water 8 is further cooled in heat exchanger 60 by a cooling stream 30/31 to condense more water out off the stream 8 that enters separator 61 as a 2-phase stream. The bottom stream 15 from the separator is flashed over valve 65 and mixed with stream 12 as explained already. The separator 61 overhead stream 10 is essentially CO₂ that is further compressed 62 before being dried 63 rendering a CO₂ stream 11 that can be compressed or pumped to whatever pressure that is required for sequestration purposes. The steam need for the process is balanced by fresh steam in stream 25.

In a simpler variation of the process described above and shown in Figure 3 the desorber overhead stream 201 is compressed 253 rendering a warm stream 202 that is used to reboil 250 the desorption column 51 leaving a 2-phase stream 203 that is separated in separator 257. The bottom stream 205 from 257 is flashed to the pressure of the desorption column 251 over valve 206 giving a 2-phase stream 207 that is separated in separator 260. This separator's bottom stream is lead to column 51 as shown. The overhead stream 208 from separator 260 is used to reboil 251 the desorption column 51 before the cooled stream 210 is pumped to the separator 257 (pump not shown). The overhead
stream from separator 257 is compressed 255 giving a warm stream 211 that is
used to raise steam 215 in heat exchanger 256 before the cooled stream 212,
that is essentially CO₂, is dried before being “sequestered” as stream 213.

Example 1:
Rich amine solution 40 containing 8.3 wt% CO₂, 27.5 wt% MEA and 64.2 wt%
H₂O mixed with recycled water stream 13 enter a stripper section 51 where
about 62% of absorbed CO₂ is stripped off by means of evaporation. Heat is
supplied in reboiler 50a/b and lean amine solution 41 containing about 3.4%
CO₂ is recycled to an absorption section (not shown). Vapour 1 containing
about 53wt% H₂O and 47 wt% CO₂ leaves the stripper column at the top.

Vapour stream 1 at 0.55 barg is compressed to 3.3 barg in a compressor 53.
Vapour 2 at 3.3 barg and 233 °C is cooled to 140 °C in a boiler 54 and further
compressed to 8 barg in a compressor 55. Vapour 4 at about 233 °C enters a
boiler/condenser 56 where about 73% of the water vapour is condensed.
Vapour/liquid mixture 5 enters a separator vessel 57 containing a demister and
is separated in one vapour stream 6 containing about 23 wt% H₂O and 77wt%
CO₂ and one liquid stream 12 containing mainly water and any MEA
entrainments. The vapour stream 6 is further compressed to 19.6 bar in
compressor 58 and cooled to 140 °C in boiler/condenser 59 and further cooled
to about 25 °C in a water cooled condenser 60. Optionally vapour stream 6 is
cooled to about 25 °C in a separate condenser (not shown). Vapour and liquid
are separated in a vessel containing a demister (not shown) before being
compressed to about 20 bar in compressor 58. Unit 59 is by-passed in this
case.

Stream 9 is separated in a vapour stream 10 containing more than 99% CO₂
and a liquid stream 15 containing mainly water. The vapour stream 10 is
compressed to about 75 bar and is further liquefied (not shown) and dried in a
unit 63.
Condensed water stream 13 at 140 °C is mixed with rich amine solution stream 40. Cold condensate stream 15 is recycled to the top of the stripper column.

Boiler feed water 20 is fed to boiler 54, boiler/condenser 56 and boiler condenser 60. Generated steam at about 2 barg and 133 °C enters reboiler 50 (section a). About 75% of required heat is supplied by steam generated in said boilers. About 25% of the steam is supplied to reboiler 50 (section b) from other sources.

**Example 2:**
Rich amine solution 118 containing 8.3 wt% CO₂, 27.5 wt% MEA and 64.2 wt% H₂O enters a stripper section 151 where about 62% of absorbed CO₂ is stripped off by means of evaporation. Heat is supplied in reboiler 150 and lean amine solution 119 containing about 3.4% CO₂ is recycled to an absorption section (not shown). Vapour 101 containing about 49 wt% H₂O and 51 wt% CO₂ leaves the stripper column at the top. Vapour stream 101 is cooled to 25 °C in heat exchanger 153 and condensed water is separated from the CO₂ containing vapour phase in unit 155. Condensed water is recycled via pump 154 to the top of the stripper column 152.

Vapour stream 103 is compressed to 75 bar in 4 compressor stages 156, 159, 162 and 165 with intermediate coolers 157, 160 and 163 and intermediate vapour/condensate separators 158, 161 and 164. The compressed CO₂ stream 113 is further liquefied (not shown) and dried in a unit 166.

The advantage of the present invention is exemplified by the following difference in energy consumption between the conventional process (Figure 1) and the novel process (Figure 2).

The heat consumption is 4 MJ/kg CO₂ recovered in both cases. Steam to electric power efficiency is estimated to 28% using low pressure steam to
generate electric power in a condensation steam turbine assuming a turbine efficiency of 90% and exit pressure of 0.025 bar.

<table>
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<th>Conventional process (Figure 1)</th>
<th>Novel process (Figure 2)</th>
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<tr>
<td>Compressor duty</td>
<td>10573 kW</td>
<td>31719 kW</td>
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<tr>
<td>Total heat consumption</td>
<td>139340 kW</td>
<td>139340 kW</td>
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<tr>
<td>Recovered heat as 3 bar steam</td>
<td>0</td>
<td>95351 kW</td>
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<td>Hot water recycle</td>
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<td>Heat import</td>
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<td>Increased power production</td>
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<tr>
<td>Increased power consumption</td>
<td>-</td>
<td>21146 kW</td>
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<tr>
<td>Increased power export</td>
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<td>Power plant fuel consumption (LHV)</td>
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<td>Power export</td>
<td>338 MW</td>
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<td>Power plant efficiency</td>
<td>49.0%</td>
<td>50.3%</td>
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Thus the present invention can increase the power plant efficiency with about 1.3 %-points.
Claims:

1. An energy efficient process for removing and sequestering CO₂ from energy process plants exhaust gas by chemical absorption and desorption, respectively, where said exhaust gas is fed to an absorber containing a chemical absorbent where the CO₂ is absorbed in said absorbent and a CO₂-depleted exhaust gas stream is formed, and the CO₂ rich absorbent is further fed to a desorber where CO₂ is removed from the absorbent, and the absorbent essentially free of CO₂ is recirculated to the absorber and the desorbed CO₂ is discharged as a CO₂ and steam containing gas stream, characterised in that said discharged CO₂ and steam containing gas stream is compressed and the (hot) compressed stream is used directly to provide reboiling for the desorber or used to raise steam from boiler feed water which can be used as heat medium in a reboiler for said desorber.

2. A process according to claim 1, characterised in that a hot condensate stream (12) is mixed into said rich absorbent stream (40) before being fed to the desorber.

3. A process according to claim 1, characterised in that a cold condensate stream (16) is recycled to the very top of the desorber.

4. A process according to claim 1, characterised in that said compression is done in two or more stages with heat recovery between stages and optionally after the last stage.
5. A process according to claim 4, characterised in that said compression is done in four stages.
Fig. 2
Fig. 3
# INTERNATIONAL SEARCH REPORT

**International application No.**

PCT/NO2006/000485

## A. CLASSIFICATION OF SUBJECT MATTER

**IPC:** see extra sheet

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)

**IPC:** B01D

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

SE, DK, FI, NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>US 4384875 A (BATEUX ET AL.), 24 May 1983 (24.05.1983)</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

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**Date of the actual completion of the international search**

18 April 2007

**Date of mailing of the international search report**

19-04-2007

**Name and mailing address of the ISA/Swedish Patent Office**

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International patent classification (IPC)

B01D 53/62 (2006.01)
B01D 53/14 (2006.01)

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Paper copies can be ordered at a cost of 50 SEK per copy from PRV InterPat (telephone number 08-782 28 85).

Cited literature, if any, will be enclosed in paper form.
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