

DESCRIPTION

Title of the invention: Capture system of carbon dioxide from a gas containing carbon dioxide

BACKGROUND OF THE INVENTION5 **Field of the Invention**

The present invention relates to the field of treatment of gases containing carbon dioxide, more specifically to a capture system of carbon dioxide from said gases containing carbon dioxide.

Description of the Related Art

10 When a source of carbon dioxide emission, for example of combustion gas, is running, for example a vehicle such as a floating structure, carbon dioxide containing gases are generated. These carbon dioxide containing gases are generally released into the atmosphere. However, it is known that carbon dioxide generates environmental damage when it is released into the atmosphere.

15 In addition to the ecological issue, this release into the atmosphere is a waste of energy, because carbon dioxide has several functions in various technical fields and can be used, for example, as a coolant or other uses.

Thus, it can be wise to treat carbon dioxide containing gases from a source of emission to extract carbon dioxide and store it for later use or commercialization. However, a
20 system that makes it possible to liquefy carbon dioxide is cumbersome and consumes a vast amount of energy, because it requires a cooling to very low temperature the carbon dioxide containing gases emitted from the source.

SUMMARY OF THE INVENTION

The present invention makes it possible to capture the carbon dioxide from a gas
25 containing carbon dioxide, hence proposes a system to capture carbon dioxide from a gas containing carbon dioxide, comprising at least a first heat exchanger and a second heat exchanger, wherein each of the heat exchangers comprises at least a chamber, a first line and a second line that both extend through the chamber, characterized in that the first heat exchanger and the second heat exchanger are configured to be operated in
30 a first operating mode, where the chamber is so configured that a gas flow containing

carbon dioxide flows through it and to capture by desublimation the carbon dioxide from said carbon dioxide containing gas flow in order to generate a decarbonized gas flow, and in a second operating mode, wherein a/the gas flow containing carbon dioxide flows through the first line and/or the second line to melt the carbon dioxide captured in the chamber, the capture system comprising control means configured to operate an alternation between the first operating mode and the second operating mode.

Thanks to the capture system according to the invention, the carbon dioxide in the carbon dioxide containing gases is captured by desublimation, then is melted for recovery at liquid state. Desublimation is the state change of a body from the gas state to the solid state without passing through the liquid state. Thus, carbon dioxide is recovered instead of being released into the atmosphere. The first heat exchanger and the second heat exchanger are specifically designed to induce the desublimation of a component, for example a fluid. When either one of the heat exchangers is operated according to the first operating mode, the cooling parameters relating to this heat exchanger allow the desublimation of carbon dioxide. Then, desublimized carbon dioxide, i.e. solid carbon dioxide, settles onto the walls of the heat exchanger in the first operating mode. In order to generate the desublimation when the carbon dioxide containing gas flows through the chamber of one and/or the other heat exchanger, at least one fluid flows through the first line and/or the second line of one and/or the other heat exchanger at a temperature low enough to cool down the carbon dioxide containing gas flow, so that the carbon dioxide component passes directly from vapor state to solid state.

Since the carbon dioxide was captured, the carbon dioxide containing gas flow through the chamber goes out decarbonized. Since it flowed through the chamber of the heat exchanger, the decarbonized gas flow goes out at very low temperature, for example -120°C. The decarbonized gas flow can then be circulated for one or several later thermal treatments, for example by heat exchange.

Thus, it shall be understood that the decarbonized gas flow is a gas flow with a lower content of carbon dioxide than that of the carbon dioxide containing gas flow because of the capture of carbon dioxide by desublimation in the heat exchanger, with additional external cold from liquefied natural gas or a refrigerant fluid from a refrigeration unit. As a non-limitative example, the carbon dioxide containing gas flow can have a 3 to 4%mol carbon dioxide content. The decarbonized gas flow from the capture system

according to the invention does no longer contain carbon dioxide, or may have a very low residual content of carbon dioxide, ca. 0.2 to 0.3%mol.

In the context of the invention, the chamber shall be understood as a zone of thermal transfer between a cold flow and a hot flow. This chamber can be materialized by walls that physically delineate the zone, as pictured in the figures and described below.

However, the chamber may also not have walls. In this case, the chamber is a zone of thermal transfer at the implementation of the first operating mode between, on one hand, the carbon dioxide containing gas flow and, on the other hand, the decarbonized gas flow and/or a flow of any other refrigerant fluid. A heat exchanger with such a chamber is called a multiflow chamber. Similarly, the case with a pipe with a refrigerant fluid flowing through it, around which there is a ring-shaped space with fins, wherein the carbon dioxide containing gas is to circulate through this ring-shaped space, is not beyond the scope of the invention. Thus, a person skilled in the art shall understand that all the line and the ring-shaped space constitutes the heat exchanger, thus the chamber is the thermal exchange zone around the line.

During the second operating mode of either one of the heat exchangers, the solid carbon dioxide, or desublimized carbon dioxide, that previously settled onto the walls of said heat exchanger, is melted, which means that it passes from solid state to liquid state.

To melt carbon dioxide, a carbon dioxide containing gas flows through the first line and/or the second line in order to warm up the chamber of the heat exchanger where solid-state carbon dioxide must be melted. In the case of an internal combustion engine, the carbon dioxide containing gas flows through the first line and/or the second line can have, for example, an input temperature between the combustion temperature of the internal combustion engine and -33°C.

The capture system is configured so that the gas flow containing carbon dioxide which passes through the chamber during the first operating mode is the same gas flow as the gas flow containing carbon dioxide passing through the first line and/or the second line during the second operating mode. In other words, the capture system is configured so that the gas flow containing carbon dioxide first flows through the first line and/or the second line of at least one of the heat exchangers operated in the second operating mode in order to melt the carbon dioxide which has been captured in the chamber, then this same gas flow containing carbon dioxide also flows through the chamber of at least one of the heat exchangers operated in the first operating mode.

As described, the first heat exchanger and the second heat exchanger can be operated according to two different operating modes: a first operating mode that makes it possible to capture carbon dioxide by desublimation, and a second operating mode that allows the melting of the captured carbon dioxide and its recovery. The control means
5 allow the management of each of these two operating modes by applying either one of them to the heat exchangers, but by switching from one of these operating modes to the other one too.

According to a characteristic of the invention, the control means are configured to operate an alternation between a heat exchanger and another one between the first
10 operating mode and the second operating mode. The alternation of the two heat exchangers and of their respective operating modes is set, so that each of the operating modes is always active in time, either on one of the heat exchangers or on the other one. Thus, carbon dioxide can be continuously captured, which prevents periods where the carbon dioxide containing gas flow cannot be treated. The control means so work that
15 when the capture system comprises only two heat exchangers, a switching of the operating mode is simultaneously implemented on the two heat exchangers. In other words, when the first heat exchanger captures carbon dioxide, the second heat exchanger is operated to melt the previously captured carbon dioxide. Once this operation is completed, the control means switch the operating mode of each of the
20 heat exchangers.

According to a characteristic of the invention, the control means comprise at least one management means configured to regulate a circulation of a first coolant that flows through either one of the lines of either one of the heat exchangers. The management means allows or prevents the circulation of the first coolant through one of the lines.
25 Thus, it shall be understood that the circulation is allowed by the management means when the considered heat exchanger is operated according to the first operating mode. Advantageously, the capture system comprises a management means per heat exchanger.

According to a characteristic of the invention, the management means comprises at least
30 a first valve upstream from either one of the lines of either one of the heat exchangers and/or at least a second valve downstream from either one of the lines of either one of the heat exchangers. In other words, the first valve and the second valve are located on both ends of one of the lines of either one of the heat exchangers and can switch

between an open position and a closed position to allow or prevent the circulation of the first coolant through the considered line, for example the first line of either one of the heat exchangers.

5 According to a characteristic of the invention, the control means comprise at least one management device configured to regulate a circulation of a second coolant that flows through either one of the lines of either one of the heat exchangers. Similarly to the management means, the management device allows or prevents the circulation of the second coolant through one of the lines. The circulation is allowed by the management
10 device when the considered heat exchanger is operated according to the first operating mode. The second coolant can be a fluid identical or different from the first coolant as previously mentioned.

Advantageously, the capture system comprises a management device by heat exchange. Thus, preferably, the capture system comprises a management means and a management device by heat exchange, wherein the management means and the
15 management device each regulate a circulation of a coolant through one of the two lines of one of the heat exchangers.

According to a characteristic of the invention, the management device comprises at least a third valve upstream from either one of the lines of either one of the heat exchangers and/or at least a fourth valve downstream from either one of the lines of either one of
20 the heat exchangers. The third valve and the fourth valve are located on both ends of one of the lines of either one of the heat exchangers and can switch between an open position and a closed position to allow or prevent the circulation of the second coolant through the considered line, for example the second line of either one of the heat exchangers.

25 In the configuration where the capture system comprises a management means and a management device by heat exchange, the first valve, the second valve, the third valve, the fourth valve are preferably all simultaneously open when the considered heat exchanger is in the first operating mode, so that some coolant flows through each one of the two lines of said heat exchangers.

30 According to a characteristic of the invention, the first coolant and/or the second coolant can be the decarbonized gas flow. Indeed, after flowing through the chamber where carbon dioxide has been captured, the decarbonized gas flow has a very low

temperature because it has been cooled down to secure the capture of carbon dioxide. Thus, the decarbonized gas flow can be used as a coolant by flowing to the inlet of at least one of the two lines of one of the heat exchangers operated according to the first operating mode. The decarbonized gas flow has, for example, a temperature of -120°C between the outlet of the chamber and an inlet of the first line and/or of the second line.

According to a characteristic of the invention, the first coolant and/or the second coolant can be a liquefied natural gas flow or a refrigerant fluid. In the case where the capture system is laid out in a structure that produces combustion gases from the combustion of liquefied natural gas or of any other entity able to transport and/or store liquefied natural gas, said gas can be used as a means to desublimize carbon dioxide. The structure can comprise at least a transport tank and/or a storage tank for the liquefied natural gas and a means to pump liquefied natural gas from there and to make it circulate to the first line and/or to the second line of at least one of the heat exchangers to take part in the capture of carbon dioxide by desublimation. The liquefied natural gas has, for example, a temperature of -161°C before flowing through the first line and/or the second line.

In the case where the capture system is laid out in a structure that does not interact with liquefied natural gas, said structure can be equipped with a cooling circuit where another refrigerant fluid flows. So, the refrigerant fluid is treated to circulate through the first line and/or the second line of the heat exchanger at a temperature low enough, for example -125°C, to take part in the desublimation of carbon dioxide.

According to a characteristic of the invention, the control means comprise at least one monitoring means configured to regulate a circulation of the carbon dioxide containing gas flow through one and/or the other one of the lines of either one of the heat exchangers.

The monitoring means allows or prevents the circulation of the carbon dioxide containing gas through at least one of the lines of the heat exchanger. Thus, it shall be understood that the circulation is allowed by the monitoring means when the considered heat exchanger is in the second operating mode.

Advantageously, the capture system comprises a monitoring means per heat exchanger.

According to a characteristic of the invention, the monitoring means comprises at least a fifth valve upstream from either one of the lines of either one of the heat exchangers and/or at least a sixth valve downstream from either one of the lines of either one of the heat exchangers. In other words, the fifth valve and the sixth valve are located on both ends of one of the lines of either one of the heat exchangers and can switch between an open position and a closed position to allow or prevent the circulation of the carbon dioxide containing gas flow through the considered line, for example the first line of either one of the heat exchangers they are allocated to.

Advantageously, the monitoring means comprises four valves, two of them upstream from both lines of either one of the heat exchangers and two of them downstream of the two lines of either one of the heat exchangers, so that the carbon dioxide containing gas flows through the two lines for better homogeneity of the melting of the captured carbon dioxide.

All valves above can be independent from each other and may be assembled, for example as a three-way valve.

According to a characteristic of the invention, the control means comprise at least one monitoring device configured to regulate the circulation of the carbon dioxide containing gas flow through either one of the heat exchangers around either one of its lines. In other words, the monitoring device regulates the circulation of the carbon dioxide containing gas flow through the chamber that goes out as the decarbonized gas flow. Thus, the monitoring device allows the circulation of the carbon dioxide containing gas flow only when the considered heat exchanger is operated according to the first operating mode.

According to a characteristic of the invention, the monitoring device comprises at least a seventh valve upstream from the chamber of either one of the heat exchangers and/or at least an eighth valve downstream from the chamber of either one of the heat exchangers. In other words, the seventh valve and the eighth valve are located on both ends of the chamber of either one of the heat exchangers and can switch between an open position and a closed position to allow or prevent the circulation of the carbon dioxide containing gas flow through the chamber.

According to a characteristic of the invention, the capture system comprises a first thermal exchanger configured to operate an exchange of heat between the carbon

dioxide containing gas flow and the decarbonized gas flow, wherein the first thermal exchanger comprises a first line through which a carbon dioxide containing gas flows and a second line through which the decarbonized gas flow flows, said first line being located upstream from the chamber of either one of the heat exchangers and said
5 second line being located downstream from the chamber. The first thermal exchanger makes it possible to cool down the carbon dioxide containing gas flow to a temperature close to the desublimation temperature of carbon dioxide while maintaining the carbon dioxide containing gas flow in gas state. Thereafter, when the carbon dioxide containing gas flows through the chamber of one of the heat exchangers operated according to the
10 first operating mode, the desublimation of carbon dioxide is made easier thanks to the very low temperature of the carbon dioxide containing gas flow at the inlet of the chamber thanks to the first thermal exchanger.

The heat exchange in the first thermal exchanger also implies the decarbonized gas flow out of the chamber of one of the heat exchangers operated according to the first
15 operating mode. Since flowing through said chamber decreased the temperature of the decarbonized gas flow, it can be used to cool down the carbon dioxide containing gas flow.

According to a characteristic of the invention, the capture system comprises a regulation device for the temperature of the carbon dioxide containing gas upstream from the first
20 line of the first thermal exchanger, configured to regulate the temperature of the carbon dioxide containing gas after flowing through the first line and/or the second line of either one of the heat exchangers, the regulation device comprising a bypass line of the first line and/or of the second line of either one of the heat exchangers, a monitoring valve configured to monitor a circulation of the carbon dioxide containing gas flow
25 through the bypass line, and a detection means of the temperature of the carbon dioxide containing gas flow upstream from the first line of said thermal exchanger.

The regulation device makes it possible to monitor the temperature of the carbon dioxide containing gas flow in order to prevent the captured carbon dioxide from melting too fast when the considered heat exchanger is in the second operating mode.

This parameter is checked by measuring the temperature of the carbon dioxide
30 containing gas flow thanks to the temperature detection means at the outlet of the first line and/or of the second line of the heat exchanger in the second operating mode. If the measured temperature is too low, it means that the melting of the carbon dioxide is

happening too fast. In this case, the regulation device can open the monitoring valve, so that the carbon dioxide containing gas flow flows in the bypass line and so bypasses the heat exchanger instead of circulating through the first line and/or through the second line to melt the captured carbon dioxide in the chamber.

5 According to a characteristic of the invention, the capture system comprises a recovery line connected to each of the heat exchangers and configured to collect the liquid-state carbon dioxide from at least one of the heat exchangers, wherein the recovery line comprises a recovery valve. When the captured carbon dioxide is melted in the chamber, it flows in liquid state through the recovery line to a storage means, for
10 example a tank or a reservoir. The recovery line comprises a recovery valve that is open only when carbon dioxide must flow in liquid state through the recovery line. Thus, the recovery valve is open only when the considered heat exchanger is in the second operating mode. The opening and/or closing of the recovery valve can be monitored by the control means.

15 According to a characteristic of the invention, the capture system is associated to a source of emission of the carbon dioxide containing gas flow, said carbon dioxide containing gas flow flowing from said source of emission. The source of emission can be an internal combustion engine, for example an engine used for the propelling of a vehicle and/or to create a power supply or for any other function. The combustion
20 engine works thanks to a fuel, and the resulting internal combustion generates the carbon dioxide containing gas flow. The source of emission can also be, non-exhaustively, a chimney, a boiler or any factory.

According to a characteristic of the invention, the capture system comprises a third heat exchanger configured to be operated according to the first operating mode and
25 according to the second operating mode, wherein the monitoring means are configured to operate an alternation between the first operating mode and the second operating mode on the third heat exchanger. This is an alternative to what has been described above, where the capture system comprises three heat exchangers instead of two. Integrating a third heat exchanger makes it possible to reduce the alternations between
30 the first operating mode and the second operating mode for each of the heat exchangers in time. Furthermore, adding a third heat exchanger also makes it possible to increase the capacity of treatment of the structure.

The scope of the invention also covers a process to capture carbon dioxide from a carbon dioxide containing gas flow implemented by a capture system of carbon dioxide from the carbon dioxide containing gas as previously described, wherein:

- 5 - at least one of the heat exchangers is operated according to the first operating mode in order to desublimize the carbon dioxide in the carbon dioxide containing gas flow through the chamber of said heat exchanger;
- 10 - an operating mode is switched from the first operating mode to the second operating mode of said heat exchanger in order to melt the desublimized carbon dioxide in the chamber by circulating the carbon dioxide containing gas flow through the first line and/or through the second line of said heat exchanger.

Thus, such a process makes it possible to capture the carbon dioxide from the carbon dioxide containing gas flow thanks to the first operating mode. Each of the heat exchangers has a maximal capacity of capture of solid or desublimized carbon dioxide.

15 This way, the switching to the second operating mode makes it possible to melt the captured carbon dioxide, hence to remove the previously captured carbon dioxide from the chamber. When it is done, the chamber is able to capture carbon dioxide again and the heat exchanger is operated according to the first operating mode again in order to capture the carbon dioxide in the carbon dioxide containing gas flow.

20 According to a characteristic of the process, at least one of the heat exchangers is in the first operating mode when the other heat exchanger is in the second operating mode. The capture process is implemented so that the carbon dioxide can be continuously captured by desublimation, so that the carbon dioxide containing gas flow is never released into the atmosphere. When the capture system comprises two heat exchangers, 25 the first heat exchanger is in the first operating mode while the second heat exchanger is in the second operating mode, and the switching between the two heat exchangers to the other operating mode is advantageously simultaneous. This makes it possible to always have at least one of the heat exchangers able to capture the carbon dioxide from the carbon dioxide containing gas flow.

30 According to a characteristic of the process, the first operating mode followed by the second operating mode constitute a capture/melting cycle of the carbon dioxide, said capture/melting cycle being repeated by iterations. The capture/melting cycle

guarantees an alternation of the heat exchangers between the first operating mode and the second operating mode continuously and with no interruption. Thus, carbon dioxide can be continuously captured, no matter how long the source of emission of the carbon dioxide containing gas flow works.

5 According to a characteristic of the process, when it is implemented by a capture system comprising three heat exchangers, two heat exchangers are in the first operating mode while the last heat exchanger is in the second operating mode, the capture/melting cycle comprising three periods of use, with two corresponding to the first operating mode and one corresponding to the second operating mode, the three periods of use being of
10 equal or substantially equal durations, the capture/melting cycle being operated so that each of the three heat exchangers is operated according to each of the three period of use and that there is a simultaneous transition between periods of use for the three heat exchangers.

In other words, in a capture system with three heat exchangers, the capture system is
15 configured so that two heat exchangers are always in the first operating mode, the remaining heat exchanger being in the second operating mode. Each heat exchanger has its own capture/melting cycle repeating in time. This is the same cycle capture/melting for all three heat exchangers: two periods under the first operating mode, followed by a period under the second operating mode. However, the capture/melting cycles of each
20 three heat exchangers are offset from one another. This offset makes it possible to set a configuration, where two heat exchangers are systematically operated according to the first operating mode as long as the capture system is working. Such a configuration makes it possible to optimize the amount of captured carbon dioxide. That's why the capture/melting cycle is divided in three periods of use.

25 The capture system is so configured that the first operating mode is maintained twice as long as the second operating mode. Thus, the first operating mode lasts two periods of use that can be defined as a first period of capture of carbon dioxide and a second period of capture of carbon dioxide, while the second operating mode lasts one period of use that can be defined as a period of melting of the captured carbon dioxide. In
30 other word, the melting of desublimized carbon dioxide takes half the time it needs for its capture.

The simultaneous transition between each period and the offset of the cycles of each heat exchanger are configured so that, at each period, a heat exchanger is working at its

first period of capture of carbon dioxide, a heat exchanger is working at its second period of capture of carbon dioxide and a heat exchanger is at its period of melting of captured carbon dioxide. So, this configuration makes it possible to optimize the capture system and to maximize the flowrate of captured carbon dioxide.

5 According to a characteristic of the process, a first coolant and a second coolant flow respectively through the first line and the second line of at least one of the heat exchangers when it is in the first operating mode. The coolants make it possible to cool down the carbon dioxide containing gas flow through the chamber in order to capture the carbon dioxide by desublimation. Thus, said coolants must circulate through the
10 first line and/or the second line at a temperature suitable for the desublimation of carbon dioxide when the carbon dioxide containing gas flow flows through the chamber, for example -120°C for a flow of decarbonized gas or -161°C for a flow of liquefied natural gas.

According to a characteristic of the process, the first valve, the second valve, the third
15 valve, the fourth valve, the seventh valve and the eighth valve are open while the fifth valve, the sixth valve and the recovery valve are closed when the considered heat exchanger is in the first operating mode. The first valve, the second valve, the third valve, the fourth valve must be open to allow the circulation of the coolant through the first line and through the second line of the considered heat exchanger. The seventh
20 valve and the eighth valve are also open to allow the circulation of the carbon dioxide containing gas flow through the chamber. The recovery valve is closed to keep the chamber watertight during the first operating mode.

According to a characteristic of the process, the first valve, the second valve, the third
25 valve, the fourth valve, the seventh valve and the eighth valve are closed while the fifth valve, the sixth valve and the recovery valve are open when the considered heat exchanger is in the second operating mode. When the heat exchanger is in the second operating mode, the first valve, the second valve, the third valve, the fourth valve, the seventh valve and the eighth valve are closed to prevent the circulation of the coolant through the lines and the carbon dioxide containing gas flow flowing through the
30 chamber.

The fifth valve and the sixth valve are open so that the decarbonized gas flow flows through the first line and/or through the second line of the considered heat exchanger in order to melt the previously captured carbon dioxide in the chamber. At this stage,

for example, the carbon dioxide containing gas flow has a temperature between -25°C and -33°C . This temperature is enough to melt carbon dioxide. Then, after flowing through the first line and/or the second line of the heat exchanger in the second operating mode, the carbon dioxide containing gas flow circulates until across the chamber of another heat exchanger that is in the first operating mode. At the same time, the recovery valve is open, so that liquid-state carbon dioxide can be collected when flowing through the recovery line.

According to a characteristic of the process, the temperature regulation device monitors an opening section of the monitoring valve in order to calculate a flowrate of the carbon dioxide containing gas flow through the first line and/or the second line of the heat exchanger that is operated according to the second operating mode and a flowrate of the carbon dioxide containing gas flow through the bypass line, the opening section of the monitoring valve depending on at least a temperature of the carbon dioxide containing gas flow as measured by the temperature detection means. So, the temperature regulation device makes it possible to monitor the speed of melting of the captured carbon dioxide in the chamber of the heat exchanger in the second operating mode, as a function of temperature measured by the temperature detection means of the carbon dioxide containing gas flow at the outlet of the first line and/or of the second line. The larger the opening section of the monitoring valve, the bigger the flowrate of the carbon dioxide containing gas flow through the bypass line. This makes it possible to restrict the flowrate of the carbon dioxide containing gas flow through the first line and/or through the second line of the heat exchanger in the second operating mode, so to slow down the melting of the captured carbon dioxide. If the monitoring valve is fully closed, the carbon dioxide containing gas flow fully circulates through the first line and/or the second line of the heat exchanger in the second operating mode.

According to a characteristic of the process, the melted carbon dioxide from the heat exchanger in the second operating mode is stored. Once the carbon dioxide melted, it flows in liquid state through the previously mentioned recovery line to be stored in a storage means.

BRIEF DESCRIPTION OF THE DRAWINGS

Other characteristics and advantages of the invention will appear thanks to the following description, on one hand, and thanks to several embodiments produced as a

guide and non-limitative with a reference to the appended schematic pictures, on the other hand, where:

[fig 1] shows a first embodiment of a system to capture carbon dioxide from a carbon dioxide containing gas flow according to the invention,

5 [fig 2] illustrates a first example of circulation of the various fluids through the first embodiment of the capture system,

[fig 3] illustrates a second example of circulation of the various fluids through the first embodiment of the capture system,

10 [fig 4] shows a second embodiment of a capture system according to the invention and an illustration of a circulation of the various fluids through this second embodiment,

[fig 5] shows a third embodiment of a capture system according to the invention and an illustration of a circulation of the various fluids in this third embodiment,

15 [fig 6] is a graph that shows the succession of the capture/melting cycles implemented by process to capture carbon dioxide in the second operating mode of the capture system.

DETAILED DESCRIPTION OF THE INVENTION

The present document uses the words upstream and downstream to define the relative position of the components. These words are to be considered relatively to the flowing direction of the fluid through these components or through the relevant circuit.

20 Figure 1 shows a first embodiment of a system 1 to capture carbon dioxide from a carbon dioxide containing gas according to the invention. For example, such a capture system 1 can be integrated in a vehicle, a chimney, a plant, or any other entity that comprises a source of emission 6 of carbon dioxide containing gas. For example, the source of emission 6 can be a combustion engine, such as an engine to propel a vehicle
25 or the engine of an electrical generator of said vehicle.

When the source of emission 6 is working, the fuel is burnt and the source of emission 6 naturally emits carbon dioxide containing gases, for example combustion gases. The capture system 1 makes it possible to capture the carbon dioxide in a carbon dioxide containing gas flow 2 instead of releasing said flow directly into the atmosphere.

In order to treat the carbon dioxide containing gas flow, it circulates from the source of emission 6 to the capture system 1 according to the invention through a pipe. Before reaching the capture system 1, the carbon dioxide containing gas flow is compressed by a compression device, not pictured in figure 1, in order to reach a pressure of ca. 4.5 bar. The carbon dioxide containing gas flow 2 can also circulate through a drying device, also not pictured, which guarantees the removing of possible trace water from the carbon dioxide containing gas flow.

The capture system 1 is pictured in figure 1 without showing the circulation of the various flows. Thus, this figure shows the components of the system without any circulation of fluid.

In order to guarantee the capture of the carbon dioxide from the carbon dioxide containing gas flow 2, the capture system 1 comprises at least two heat exchangers 4, in particular a first heat exchanger 4a and a second heat exchanger 4b.

Each heat exchanger 4 comprises a chamber 14 defined by an internal volume of each of the heat exchangers 4 and two lines 12 that extend through the chamber 14. More precisely, each heat exchanger 4 comprises a first line 12a and a second line 12b through which a fluid can circulate. The first line 12a and the second line 12b both cross the chamber 14. A heat exchanger can then be implemented between the lines 12 and the chamber 14.

The heat exchangers 4 have the particularity of being operated according to two operating modes. A first operating mode implements the capture of the carbon dioxide from the carbon dioxide containing gas flow 2 by desublimation. The carbon dioxide containing gas 2 flows across the chamber 14 of either one of the heat exchangers 4 and the carbon dioxide the carbon dioxide containing gas flow 2 is made of is desublimized and deposits in solid state onto the walls of the considered heat exchanger 4.

In order to desublimize the carbon dioxide in the carbon dioxide containing gas flow 2, coolants flow through the first line 12a and/or the second line 12b. They guarantee the cooling of the carbon dioxide containing gas flow 2 through the chamber 14 in order to provide the temperature condition suitable for the capture of carbon dioxide by desublimation. This allows the generation of a decarbonized gas flow 3 at the outlet of the chamber 14 of the heat exchanger 4.

The heat exchangers 4 can also be operated in a second operating mode that guarantees a melting of the previously captured carbon dioxide in the chamber 14 of the considered heat exchanger 4. Preferentially, the second operating mode is implemented on a heat exchanger 4 previously operated in the first operating mode.

5 In order to melt the carbon dioxide captured by melting, the carbon dioxide containing gas flow 2 flows through the first line 12a and/or the second line 12b of the heat exchanger 4. Since the carbon dioxide containing gas flow has a relatively high temperature, for example around between -25°C and -33°C, the chamber 14 receives the heat that the carbon dioxide containing gas flow yields by cooling, and the captured
10 carbon dioxide becomes liquid.

That's why the capture system 1 comprises a recovery line 31 connected to the chamber 14 of each of the heat exchangers 4 that circulates liquid carbon dioxide to a storage means 53. Thus, in addition to preventing the release of carbon dioxide into the atmosphere, the capture system 1 according to the invention makes it possible to store
15 the carbon dioxide in liquid state, which can later be used or commercialized for various other activities. The recovery line 31 comprises a recovery valve 19 that can be open to allow the circulation of liquid carbon dioxide into the recovery line 31.

In order to operate the heat exchangers 4 in either one of the operating modes, but also to switch said heat exchangers 4 from an operating mode to the other, the capture
20 system 1 comprises control means 5 that make it possible to manage the circulation of the various fluids through the lines 12 and/or through the chamber 14 of each of the heat exchangers 4.

The control means 5 notably comprise at least one management means 42, at least one management device 40, at least one monitoring means 38 and at least one monitoring
25 device 44. Advantageously, there are as many of each of the control means 5 as heat exchangers 4, so that each of them can be operated in either one of the operating modes above.

The management means 42 makes it possible to monitor the circulation of a first coolant that flows through either one of the lines 12 of the heat exchangers 4. For
30 example, in figure 1, there is a management means 42 for each heat exchanger 4, and each of the management means 42 monitors the circulation of the first coolant through the first line 12a. Each management means 42 comprises a first valve 42a and a second

valve 42b on both ends of the first line 12a of each heat exchanger 4, which means upstream and downstream from the first line 12a.

The management means 40 makes it possible to monitor the circulation of a second coolant, that can be identical or different from the first coolant, through either one of the lines 12 of the heat exchangers 4. For example, in figure 1, there is a management means 40 for each heat exchanger 4, and each of the management means 40 monitors the circulation of the second coolant through the second line 12b. Each management device 40 comprises a third valve 40a and a fourth valve 40b on both ends of the second line 12b of each heat exchanger 4, which means upstream and downstream from the second line 12b.

Thus, it shall be understood that the first valve 42a, the second valve 42b, the third valve 40a and the fourth valve 40b are open to allow the circulation of the coolants when the considered heat exchanger 4 is in the first operating mode, wherein the flow of the coolants through the lines 12 induces the capture of the carbon dioxide by desublimation.

The monitoring means 38 makes it possible to monitor the circulation of the carbon dioxide containing gas flow 2 through one and/or the other of the lines 12 of the heat exchangers 4. For example, in figure 1, there is a monitoring means 38 for each heat exchanger 4, and each of the monitoring means 38 monitors the circulation of the carbon dioxide containing gas flow 2 through the first line 12a and/or through the second line 12b. Each monitoring means 38 comprises at least a fifth valve 38a and a sixth valve 38b located on both ends of one or the other of the lines 12 of each heat exchanger 4, which means upstream and downstream from either one of the lines 12. Advantageously, as pictured on figure 1, each monitoring means 38 comprises two fifth valves 38a and two sixth valves 38b, which means a fifth valve 38a and a sixth valve 38b upstream and downstream from each of the lines 12 of the considered heat exchanger 4.

Thus, it shall be understood that the fifth valves 38a and the sixth valves 38b are open to allow the circulation of the carbon dioxide containing gas flow 2 through the lines 12 when the considered heat exchanger 4 is in the second operating mode, wherein the carbon dioxide containing gas flow 2 through the lines 12 induces the melting of the captured carbon dioxide in the chamber 14 of the considered heat exchanger 4.

In the figures 1 to 5, all valves above are independent from each other and some of them may be assembled, for example as three-way valves.

The monitoring means makes it possible to monitor the circulation of the carbon dioxide containing gas flow 2 through the chamber 14 of the heat exchangers 4. More precisely, it is the carbon dioxide containing gas flow 2 that flows through the chamber 14 around the lines 12 and that is cooled down to capture the carbon dioxide by desublimation. For example, in figure 1, there is a monitoring device for each heat exchanger 4. Each monitoring means comprise at least a seventh valve 44a and an eighth valve 44b located on both sides of the chamber 14 of each heat exchanger 4, which means upstream and downstream from the chamber 14 of each heat exchanger 4.

Thus, it shall be understood that the seventh valve 44a and the eighth valve 44b are open to allow the circulation of the carbon dioxide containing gas flow 2 through the chamber 14 when the considered heat exchanger 4 is in the first operating mode, wherein the carbon dioxide containing gas flow 2 through the chamber 14 makes it possible to capture the carbon dioxide it holds.

It should be noted that the management means 42, the management device 40, the monitoring means 38 and the monitoring device are no material objects but only denominations to call each of the valves above. Furthermore, the recovery valve 19 above can also be monitored by the control means 5.

No matter the embodiment of the invention or its variants, there is a regulation means 90, whose role is to control the temperature in at least one of the two chambers 14a, 14b, and advantageously in a unique chamber or in all the chambers in the first operating mode. By controlling the temperature in the chamber 14, it is possible to act on the desublimation that takes place in this chamber 14. To do so, the regulation means 90 comprises at least one channel 93 that makes a part of the decarbonized gas flow 3 bypass the one or several lines 12 of the one or several heat exchangers 4 according to the considered embodiment. Thus, the flowrate through the one or several lines 12 can be reduced, which means the supply of cold into the chamber 14 can be adjusted.

The circulation of the decarbonized gas flow through this channel 93 depends on a measurement means 91 for the temperature in at least one of the two chambers 14, 14a, 14b. This measurement means 91 is, for example, a temperature sensor in the chamber

14. This measurement means 91 acts on a regulation valve 92 located on the channel 93 and that adjusts the flowrate of the decarbonized gas flow 3 through the channel 93.

The capture system 1 further comprises a first thermal exchanger 16 and a second thermal exchanger 10, each of them being configured to operate an exchange of heat
 5 between the carbon dioxide containing gas flow 2 and the decarbonized gas flow 3 after this one goes out of the chamber 14 of at least one heat exchanger 4 in the first operating mode.

Since the decarbonized gas flow 3 has a very low temperature because it has circulated through the chamber 14 of one of the heat exchangers 4 in the first operating mode, the
 10 first thermal exchanger 16 and a second thermal exchanger 10 make it possible to use this temperature of the decarbonized gas flow 3 to pre-cool down the carbon dioxide containing gas flow 2 before it flows through the chamber 14 of a heat exchanger 4 in the first operating mode. Thus, a first thermal exchanger 16 comprises a first line 16a through which the carbon dioxide containing gas flow 2 flows, and a second line 16b
 15 through which the decarbonized gas flow 3 flows, and the second thermal exchanger 10 comprises a first line 10a through which the carbon dioxide containing gas flow 2 flows and a second line 10b through which the decarbonized gas flow 3 flows. As detailed later, the second thermal exchanger 10 is located upstream from the first thermal exchanger 16 relatively to the direction of flow of the carbon dioxide containing gas
 20 flow 2.

Figure 2 shows the same capture system 1 as illustrated in figure 1. However, figure 2 illustrates a first example of circulation of the various fluids through the capture system 1 when it is working.

In the figures 2 to 5, the thick plain lines are where the carbon dioxide containing gas flow 2 flows, the thin plain lines are where the decarbonized gas flow 3 flows, mixed
 25 lines are where liquefied natural gas flows, long dotted lines correspond to a flow of liquid carbon dioxide, and short dotted lines correspond to pipes where there is no circulation of any fluid in the considered operating mode.

In the figure 2, the second heat exchanger 4b is operated by the control means 5 in the
 30 first operating mode. In other words, the capture of the carbon dioxide from the carbon dioxide containing gas flow 2 is happening in the chamber 14b of the second heat exchanger 4b. The first heat exchanger 4a is operated by the control means 5 in the

second operating mode. In other words, some carbon dioxide has previously been captured in the chamber 14a of the first heat exchanger 4a, and said carbon dioxide is melting.

5 When the carbon dioxide containing gas flow 2 is emitted by the source of emission 6, it circulates to the capture system 1 after previous compression and drying as mentioned above. At the inlet of the capture system 1, the carbon dioxide containing gas flow 2 has a temperature, for example, between +5°C and +15°C.

10 Then, the carbon dioxide containing gas flow 2 flows through the capture system 1, more precisely through a first supply circuit 8. The first supply circuit 8 is divided in a first line 8a and a second line 8b and fluidically connects the inlet of carbon dioxide containing gas flow 2 to the heat exchangers 4.

The carbon dioxide containing gas flow 2 flows through the first line 8a to the second thermal exchanger 10, where it is pre-cooled by the decarbonized gas flow 3 down to a temperature of ca. -33°C.

15 The carbon dioxide containing gas flow 2 keeps on flowing through the first line 8a to the first heat exchanger 4a. The control means 5, in particular the monitoring means 38 associated with the first heat exchanger 4a, is configured to keep the fifth valves 38a and the sixth valves 38b on both ends of the lines 12 of the first heat exchanger 4a open. This configuration allows the carbon dioxide containing gas flow 2 to circulate through
20 the first line 12a and the second line 12b of the first heat exchanger 4a. Since the carbon dioxide containing gas flow 2 has a temperature between -25°C and -33°C, an exchange of heat is operated that cools the carbon dioxide containing gas flow 2 down, for example to a temperature between -42°C and -49°C, while warming up the chamber 14a of the first heat exchanger 4a, which leads to the melting of the carbon dioxide in said
25 chamber 14a of the first heat exchanger 4a. The liquid carbon dioxide produced this way can circulate through the recovery line 31 to the storage means 53 with the recovery valve 19 of the first heat exchanger 4a open.

30 At the outlet of the lines 12 of the first heat exchanger 4a, the carbon dioxide containing gas flow 2 keeps on flowing to the first thermal exchanger 10 where it is once again cooled down by the decarbonized gas flow 3. The carbon dioxide containing gas flow 2 is cooled down to a threshold temperature of state change of carbon dioxide, for example to a temperature of ca. -99°C.

Then, the carbon dioxide containing gas flow 2 flows to the second heat exchanger 4b. The control means 5, in particular the monitoring device associated with the second heat exchanger 4b, is configured to keep the seventh valves 44a and the eighth valves 44b on both sides of the chamber 14b of the second heat exchanger 4b open, so that the carbon dioxide containing gas flow 2 can flow through it.

When the carbon dioxide containing gas flow 2 flows through the chamber 14b of the second heat exchanger 4b, an exchange of heat is operated, because the first coolant and the second coolant flow through the lines 12 of the second heat exchanger 4b. The carbon dioxide containing gas flow 2 is then cooled down to such a temperature that the carbon dioxide in the carbon dioxide containing gas flow 2 is desublimized, which means that it passes from vapor state to solid state. Then, the carbon dioxide settles as a frost onto the walls of the chamber 14b of the second heat exchanger 4b and around its lines 12. The details about the characteristics and the nature of the coolants are described below.

The passage through the chamber 14b of the second heat exchanger 4b leads to the generation of the decarbonized gas flow 3 from the carbon dioxide containing gas flow 2. The decarbonized gas flow 3 has then a temperature of ca. -120°C . The capture system 1 comprises a second supply circuit 20 that circulates the decarbonized gas flow 3 through the capture system 1. The second supply circuit 20 notably comprises a line 22 that circulates the decarbonized gas flow 3 from the chambers 14 of the heat exchangers 4 to the lines 12 of the heat exchangers.

Indeed, since the decarbonized gas flow 3 is at ca. -120°C , it can be used as a coolant for at least one of the heat exchangers 4 in the first operating mode. In the figure 2, the line 22 allows the circulation of the decarbonized gas flow 3 to the first line 12a of the second heat exchanger 4b.

The control means 5, in particular the management means 42 associated with the second heat exchanger 4b, is configured to keep the first valve 42a and the second valve 42b on both ends of the first line 12a of the second heat exchanger 4b open, so that the decarbonized gas 3 can flow through it to serve as the first coolant in the second heat exchanger 4b, thus taking part in the desublimation of the carbon dioxide in the carbon dioxide containing gas flow 2. At the outlet of the first line 12a of the second heat exchanger 4b, the decarbonized gas flow 3 has a temperature of ca. -102°C . The

recovery valve 19 of the second heat exchanger 4b is closed to keep the chamber 14b watertight.

The second supply circuit 20 also comprises a collector 24 to collect the decarbonized gas flow 3 after it was evacuated from either one of the lines 12 of at least one of the heat exchangers 4 in the first operating mode: here the first line 12a of the second heat exchanger 4b. The collector 24 makes notably possible to circulate the decarbonized gas flow 3 to the first thermal exchanger 16 to cool down the carbon dioxide containing gas flow 2.

At the outlet of the first thermal exchanger 16, the decarbonized gas flow 3 has a temperature between -52°C and -55°C . It will flow to the first thermal exchanger 10 to pre-cool the carbon dioxide containing gas flow 2. At the outlet of the second heat exchanger 10, the decarbonized gas flow 3 has a temperature between -19°C and -25°C . Such a succession of heat exchanges makes it possible to take the most of the cooling capacities of the decarbonized gas flow 3. It will then flow out of the capture system 1 and can, for example, if possible, take part in the cooling of the carbon dioxide containing gas flow 2 during its compression and its drying before reaching the capture system 1.

The capture system 1 further comprises a third supply circuit 28 where a flow of liquefied natural gas 30 or of any other refrigerant fluid can circulate. The capture system 1, as mentioned above, can be integrated to a vehicle, for example a floating structure. Such a floating structure can comprise a transport and/or storage tank 34 for a liquefied natural gas. In addition, it can be used as a fuel for the source of emission 6. So, on all of the figures 2 to 5, it is a liquefied natural gas flow 30 that flows through the third supply circuit 28. However, it is possible that the third supply circuit 28 is a cooling circuit, where a refrigerant fluid flows, giving the same function to the liquefied natural gas flow 30.

The tank 34 comprises a pump 32 that circulates a liquefied natural gas flow 30. Then, it flows through the third supply circuit 28 to the heat exchanger 4. Thus, it shall be understood that the liquefied natural gas can be used as a coolant to take part in the capture of the carbon dioxide from the carbon dioxide containing gas flow 2.

In the figure 2, the liquefied natural gas flow 30 circulates to the second line 12b of the second heat exchanger 4b working in the first operating mode. The control means 5, in

particular the management device 40 associated with the second heat exchanger 4b, is configured to keep the third valve 40a and the fourth valve 40b on both ends of the second line 12b of the second heat exchanger 4b open, so that the liquefied natural gas flow 30 can flow through it to serve as the second coolant in the second heat exchanger 4b, thus taking part in the desublimation of the carbon dioxide in the carbon dioxide containing gas flow 2. At the inlet of the second line 12b of the second heat exchanger 4b, the liquefied natural gas flow 30 has a temperature of ca. -161°C . In the case where another refrigerant fluid flows through the third supply circuit 28, said refrigerant fluid can have, for example, a temperature of -125°C . At the outlet of the second line 12b of the second heat exchanger 4b, the liquefied natural gas flow 30 has a temperature of ca. -101°C .

Advantageously, the decarbonized gas flow 3 flows through the first line 12a and the liquefied natural gas 30 flows through the second line 12b of the heat exchanger 4 in the first operating mode. This design makes it possible for the carbon dioxide containing gas flow 2, when flowing through the chamber 14, to be first cooled down by the decarbonized gas flow 3, then by the liquefied natural gas 30 that is colder than the decarbonized gas flow 3. This way, the cooling of the carbon dioxide containing gas flow 2 is progressive and takes part in the spreading of the dry ice on the cold surfaces that the carbon dioxide containing gas flow 2 successively flows upon.

At the outlet of the second line 12b of the second heat exchanger 4b, the liquefied natural gas flow 30 can be used for a later heat exchange. Indeed, as previously mentioned, the first supply circuit 8 is divided in the first line 8a and the second line 8b. The circulation of the carbon dioxide containing gas flow 2 through the line 8a was described above.

The carbon dioxide containing gas flow 2 through the second line 8b also flows to the heat exchanger 4, but must be pre-cooled before flowing through the chamber 14 of at least one of the heat exchangers 4 in the first operating mode, just like the carbon dioxide containing gas flow 2 through the first line 8a.

To do so, the capture system 1 comprises a third thermal exchanger 18 configured to operate an exchange of heat between the carbon dioxide containing gas flow 2 through the second line 8b and the liquefied natural gas flow 30 through the third supply circuit 28 after it flowed through one and/or the other of the lines 12 of at least one heat exchanger 4 in the first operating mode. The division of the first supply circuit 8 into

two lines 8a, 8b makes it possible to share the pre-cooling of the carbon dioxide containing gas flow 2 between several heat exchangers. In addition, it is possible to use the low temperature of the liquefied natural gas flow 30.

Thus, the third thermal exchanger 18 comprises a first line 18a through which the carbon dioxide containing gas 2 flows, and a second line 18b through which the liquefied natural gas flow 30 flows. Since it has a temperature of ca. -101°C , it is able to cool the carbon dioxide containing gas flow 2 down to the threshold temperature of state change of carbon dioxide, for example to a temperature of ca. -99°C .

Downstream from the third thermal exchanger 18, the second line 8b joins the first line 8a downstream from the first thermal exchanger 10 and upstream from the heat exchangers 4. Thus, the carbon dioxide containing gas flows 2 that flow through each of the lines 8a, 8b are gathered at an identical or substantially identical temperature.

At the outlet of the third thermal exchanger 18, the liquefied natural gas flow 30 or any other refrigerant fluid is in vapor state at a temperature of ca. $+3^{\circ}\text{C}$ and can circulate to a reception means 35 that can warm up said flow and circulate it to a gas consumer appliance, for example the source of emission 6 that generates the carbon dioxide containing gas flow 2 that the capture system 1 according to the invention is trying to treat.

Notably in order to regulate the temperature of the gas flows at the first thermal exchanger 16, the capture system 1 is also provided with a regulation system 46 and a regulation device 61.

The regulation system 46 comprises a detection device 48, a bypass line 26 and a ninth valve 50. The detection device 48 makes it possible to measure the temperature of the carbon dioxide containing gas flow 2 at the outlet of the first thermal exchanger 16. The bypass line 26 is integrated into the second supply circuit 20 and is laid out parallel to the first thermal exchanger 16. The ninth valve 50 is located on the bypass line 26.

The function of the regulation system 46 is to prevent a premature desublimation of carbon dioxide in the first thermal exchanger 16 that is not configured to store solid-state carbon dioxide. Thus, the temperature of the carbon dioxide containing gas flow 2 is checked at the outlet of said first thermal exchanger 16. If the detection device 48 measures a temperature lower than a preset temperature threshold, it means that the

decarbonized gas flow 3 cools the carbon dioxide containing gas flow 2 too much in the first thermal exchanger 16.

To lessen such a cooling, the ninth valve 50 can be open, so that at least a fraction of the decarbonized gas flow 3 flows through the bypass line 26 instead of flowing through the first thermal exchanger 16. This restricts the flowrate of the decarbonized gas flow 3 through the first thermal exchanger 16 and prevents a too intensive cooling of the carbon dioxide containing gas flow 2.

The detection device 48 can be configured to directly monitor the ninth valve 50. It can be open to modify a cross-section of the bypass line 26. This way, it is possible to monitor the decarbonized gas flowrate through the bypass line 26, hence to indirectly monitor the decarbonized gas flowrate through the first thermal exchanger 16. In the case where the decarbonized gas flow 3 is divided in a fraction that flows through the bypass line 26 and a fraction that flows through the first thermal exchanger 16, the two fractions are gathered downstream from it, then the decarbonized gas 3 keeps on flowing to the second thermal exchanger 10.

The regulation device 61 comprises a bypass line 62 of the first line 12a and/or of the second line 12b of either one of the heat exchangers 4, a monitoring valve 63 configured to monitor the circulation of the carbon dioxide containing gas flow 2 through the bypass line 62, and a detection means 64 of the temperature of the carbon dioxide containing gas flow 2 upstream from the first thermal exchanger 16. The bypass line 62 is integrated to the first line 8a of the first supply circuit 8 and is laid out parallel to the lines 12 of the heat exchangers 4. The monitoring valve 63 is located on the bypass line 62.

The function of the regulation device 61 is to monitor the speed of the melting of the carbon dioxide in the chamber 14 of at least one of the considered heat exchangers 4 in the second operating mode. The temperature of the carbon dioxide containing gas flow 2 is monitored by the detection means 64 upstream from the first thermal exchanger 16, which means downstream from the lines 12 of at least one of the heat exchangers 4, here the first line 12a and the second line 12b of the first heat exchanger 4a. If the detection means 64 measures a temperature lower than a preset temperature threshold, it means that the carbon dioxide containing gas flow 2 operates a too intensive exchange of heat in at least one of the heat exchangers 4 in the second operating mode, thus that the melting of the carbon dioxide is potentially made too fast.

In order to lessen the speed of the melting of carbon dioxide, the monitoring valve 63 can be open, so that at least a fraction of the carbon dioxide containing gas flow 2 flows through the bypass line 62 instead of flowing through the first line 12a and the second line 12b of the first heat exchanger 4a. Thus, this restricts the flowrate of the carbon dioxide containing gas flow 2 that flows through the first line 12a and the second line 12b of the first heat exchanger 4a and prevent a too quick melting of the carbon dioxide in the chamber 14a of the first heat exchanger 4a.

The detection means 64 can be configured to directly monitor the monitoring valve 63. It can be open to modify a cross-section of the bypass line 62. This way, it is possible to monitor the flowrate of carbon dioxide containing gas through the bypass line 62, hence to indirectly monitor the flowrate of carbon dioxide containing gas through the first line 12a and through the second line 12b of the first heat exchanger 4a.

In the case where the carbon dioxide containing gas flow 2 is divided in a fraction flowing through the bypass line 62 and a fraction flowing through the first line 12a and the second line 12b of the first heat exchanger 4a, the two fractions gather downstream from it and upstream from the measurement of the temperature of the carbon dioxide containing gas flow 2 by the detection means 64. Although the temperature of the fraction of the carbon dioxide containing gas flow 2 that flows through the first line 12a and the second line 12b of the first heat exchanger 4a has been lowered during the heat exchange in it, this drop of temperature is compensated by the temperature of the fraction of the carbon dioxide containing gas flow 2 that flows through the bypass line 62 and, so, that was not submitted to a heat exchange when the two fractions are gathered and mix.

Figure 3 shows the same capture system 1 as illustrated in figure 1 and in figure 2.

Figure 3 illustrates a second example of circulation of the various fluids through the capture system 1 when it is working. The difference with figure 2 is that the first heat exchanger 4a is in the first operating mode while the second heat exchanger 4b is in the second operating mode.

Thus, it shall be understood that the configuration in figure 3 is successive to the configuration in figure 2. Indeed, the capture system 1 implements a process to capture carbon dioxide from the carbon dioxide containing gas flow, where each heat exchanger 4 is operated according to one of the operating modes and then switches to the other operating mode. Thus, this capture process allows the capture of the carbon dioxide

from the carbon dioxide containing gas flow 2 in each heat exchanger 4 in the first operating mode, then the melting of the captured carbon dioxide in said heat exchangers 4 in the second operating mode, thus constituting a capture/melting cycle. Later, the capture/melting cycle is repeated by iterations in order to continuously capture carbon dioxide in the carbon dioxide containing gas flow 2. The control means switch the heat exchangers 4 between the operating modes thanks to the opening and the closure of the various valves above.

In addition, in a capture system 1 comprising two heat exchangers 4 as pictured in the figures 1 to 3, the capture process is so configured that each of the two heat exchangers 4 is operated according to a different operating mode, and that the switching from an operating mode to another is simultaneous or substantially simultaneous at the two heat exchangers 4. Such a configuration guarantees constantly having a heat exchanger 4 in the first operating mode, thus being able to permanently capture the carbon dioxide from the carbon dioxide containing gas flow 2, since it is continuously provided as long as the source of emission 6 is working.

As an example, when switching from the configuration of figure 2 to the configuration of figure 3, the first heat exchanger 4a, which is initially operated in the second operating mode, must switch to the first operating mode. The fifth valves 38a and the sixth valves 38b on end sides of the lines 12 of the first heat exchanger 4a closed to stop the circulation of the carbon dioxide containing gas flow 2 through said lines 12. The recovery valve 19 is closed as well. The first valve 42a and the second valve 42b on both ends of the first line 12a of the first heat exchanger 4a are open to let the decarbonized gas 3 flow through the first line 12a. The third valve 40a and the fourth valve 40b on both ends of the second line 12b of the first heat exchanger 4a are open too to let the liquefied natural gas flow 30 flows through the second line 12b. At last, the seventh valve 44a and the eighth valve 44b on both sides of the chamber 14a of the first heat exchanger 4a are open to let the carbon dioxide containing gas flow 2 flows through the chamber 14a. The first heat exchanger 4a is then ready to operate in the first operating mode and to capture the carbon dioxide from the carbon dioxide containing gas flow 2 as illustrated in the figure 3.

At the same time as the switching of the operating mode of the first heat exchanger 4a, the second heat exchanger 4b, which is initially operated in the first operating mode, must switch to the second operating mode. The first valve 42a and the second valve 42b

on both ends of the first line 12a of the second heat exchanger 4b are closed to stop the decarbonized gas flow 3 through the first line 12a. The third valve 40a and the fourth valve 40b on both ends of the second line 12b of the second heat exchanger 4b are closed too to stop the liquefied natural gas flow 30 or any other refrigerant fluid through the second line 12b. The seventh valve 44a and the eighth valve 44b on both sides of the chamber 14b of the second heat exchanger 4b are closed too, to stop the carbon dioxide containing gas flow 2 through the chamber 14b.

At last, the fifth valves 38a and the sixth valves 38b on both ends of the lines 12 of the second heat exchanger 4b are open to let the circulation of the carbon dioxide containing gas flow 2 flow through said lines 12. The recovery valve 19 is also open to allow the circulation of liquid carbon dioxide into the recovery line 31. The second heat exchanger 4b is then ready to operate in the second operating mode and to melt the carbon dioxide captured in the chamber 14b as illustrated in the figure 3. All the operations to monitor the operating modes of the heat exchangers 4 and to switch from an operating mode to another are provided by operating means 5.

The switching between the operating modes of the heat exchangers 4 continues as long as the source of emission 6 is working, thus as long as there is carbon dioxide to capture. The circulation of the various fluids is identical to what is described in figure 2, but with inversion of the first heat exchanger 4a and the second heat exchanger 4b.

Figure 4 shows a second embodiment of the capture system 1 according to the invention. The second embodiment is different from the first embodiment of the figures 1 to 3, in that the capture system 1 comprises three heat exchangers 4 designed to capture or melt the carbon dioxide.

The capture system 1 comprises a third heat exchanger 4c, whose structure and function are identical to the first heat exchanger 4a and to the second heat exchanger 4b. Thus, the third heat exchanger 4c can be operated in the two above-mentioned operating modes, and the control means 5 can make the third heat exchanger 4c switch from an operating mode to another.

To have the same functional characteristics as the first heat exchanger 4a and as the second heat exchanger 4b, the third heat exchanger 4c is linked to all the various supply circuits the same way as to the first heat exchanger 4a and to the second heat exchanger 4b. The capture system 1 further comprises control means 5 associated to the third heat

exchanger 4c. Thus, the control means 5 comprise a management means 42, a management device 40, a monitoring means 38 and a monitoring device, each of them associated to the third heat exchanger 4c and each of them with its respective valves as described above.

5 Thus, the circulation of the various fluids according to the operating mode on the third heat exchanger 4c is identical as what has been described above. For example, the various fluids can divide into two fractions at the portions of different circuits when two heat exchangers 4 are in the same operating mode. That's the way it will be referred to the description of figures 1 to 3, which constitutes the support and/or the detailed
10 description of the identical items or of items that work the same way on these figures.

In the second embodiment of the capture system 1, the capture process of the carbon dioxide is implemented so that there are constantly two heat exchangers 4 that are in the first operating mode, which means two heat exchangers 4 that capture carbon dioxide in their respective chamber 14. As pictured in figure 4, the first heat exchanger 4a is in the
15 second operating mode while the second heat exchanger 4b and the third heat exchanger 4c are in the first operating mode. Having two heat exchangers 4 in the first operating mode makes it possible to treat a bigger flowrate of the carbon dioxide containing gas 2, which increases the capacity of treatment of the capture system 1. The advancement of the capture process and of the different switches of the operating mode
20 in a capture system 1 with three heat exchangers 4 is detailed below.

In this embodiment, when two heat exchangers 4 are operated in the first operating mode, the capture system 1 can comprise a flowrate sensor 94 upstream from the chamber 14 of each heat exchanger 4, for example close to the seventh valve 44a of the monitoring device of each heat exchanger 4. Each flowrate sensor 94 makes it possible
25 to measure the flowrate of the carbon dioxide containing gas flow 2 through the chamber 14 of the heat exchangers 4 in the first operating mode.

In addition, each eighth valve 44b of the monitoring device of each heat exchanger 4 can be a valve able to modify a cross-section for the decarbonized gas flow 3. This process monitors the sharing of the flowrate of the carbon dioxide containing gas flow 2
30 between the two heat exchangers 4 in the first operating mode.

Figure 5 represents a third embodiment of the carbon dioxide capture system 1 according to the invention. Relatively to what was described for the previous figures, the

second embodiment is different because there is no line 22, its role relatively to it being substituted by at least one line 54.

In this third embodiment, the first heat exchanger 4a is linked to a first line 54a, the second heat exchanger 4b is linked to a second line 54b and the third heat exchanger 4c is linked to a third line 54c. It is obvious that such a configuration for the lines 54 also applies to a capture system 1 with only two heat exchangers 4.

For each of the heat exchangers 4, the line 54 starts downstream from the chamber 14 of the considered heat exchanger 4 and is then connected to the second line 12b that extends through said chamber 14. This way, each heat exchanger 4 can receive only the decarbonized gas flow 3 it produced itself. This configuration allows operations at different temperatures, if needed, at the outlet of each heat exchanger 4. This configuration also allows to prevent interferences between the two appliances working in the first operating mode.

According to the example of fluid circulation as pictured in figure 5, the second heat exchanger 4b and the third heat exchanger 4c are in the first operating mode. The second line 54b and the third line 54c respectively channel the decarbonized gas flow 3 from the chamber 14 constitutive of the second heat exchanger 4b and from the chamber 14 constitutive of the third heat exchanger 4c, to the second line 12b of each heat exchanger 4.

Since all these structural and functional elements, except the lines 54, are identical to what was described above, it shall be referred to the description of the figures 1 to 4 to understand items common to all the embodiments of the capture system 1.

Figure 6 is a graph that details the succession of the capture/melting cycles 81 for each of the three heat exchangers 4a, 4b, 4c in time, so that there are constantly two heat exchangers in the first operating mode 101.

The graph shows the operating mode in ordinate of each of the three heat exchangers 4 in time. The time is divided in periods of use 80, all of equal duration. In figure 6, eight periods of use 80 are shown, but the periods of use 80 can be repeated as many times as required. For example, a period of use 80 can be equal to four hours.

In figure 6, the time T0 can be a random moment where the source of emission is working and carbon dioxide has to be captured. The time T0 can be, for example, the moment where the first heat exchanger 4a starts a new capture/melting cycle 81. At

time T0, the first heat exchanger 4a is in the first operating mode 101 to start the capture of the carbon dioxide from the carbon dioxide containing gas flow.

At time T1, which means after one period of use 80, a new period of use 80 starts, between the time T1 and the time T2. From the time T1 on, the second heat exchanger 4b starts a new capture/melting cycle 81 and so is in the first operating mode 101, while the first heat exchanger 4a is maintained in the first operating mode 101, and so keeps on capturing carbon dioxide.

From the time T2 on, the heat exchanger 4a, which captured a sizable quantity of carbon dioxide, switches to the second operating mode 102 so that the captured carbon dioxide in the chamber of the first heat exchanger 4a melts. At the same time, the third heat exchanger 4c starts a new capture/melting cycle 81 and is in the first operating mode 101 to capture the carbon dioxide from the carbon dioxide containing gas flow. The second heat exchanger 4b remains in the first operating mode 101 to keep on capturing carbon dioxide from its chamber.

Between the time T2 and the time T3, the first heat exchanger 4a is in the second operating mode 102 while the second heat exchanger 4b and the third heat exchanger 4c are in the first operating mode 101. Thus, the circulation of the various fluids in this period of use 80 corresponds to the circulation of fluids as pictured in figure 4.

At time T3, the first heat exchanger 4a switches back to the first operating mode 101. Since the carbon dioxide was totally melted for the previous period of use 80, the first heat exchanger 4a is able to capture carbon dioxide from the carbon dioxide containing gas flow again.

So, between the time T0 and the time T3, the first heat exchanger 4a made a complete capture/melting cycle 81. Thus, it shall be understood that a capture/melting cycle 81 lasts three periods of use 80, including two periods of use 80 where the considered heat exchanger is in the first operating mode 101, then a period of use 80 where the considered heat exchanger is in the second operating mode 102. Thus, the melting of the carbon dioxide lasts half the time of capture of the carbon dioxide.

In parallel, at time T3, the second heat exchanger 4b is in the first operating mode 101 for two periods of use 80 and then switches to the second operating mode 102 so that carbon dioxide melts. Since it has been operated in the first operating mode 101 only

for a first period of use 80, the third heat exchanger 4c remains in the first operating mode 101.

At time T4, the second heat exchanger 4b switches back to the first operating mode 101 to complete its capture/melting cycle 81 and starts one anew. Thus, the carbon dioxide is once again captured in the chamber of the second heat exchanger 4b.

In turn, the third heat exchanger 4c switches to the second operating mode 102 so that the captured carbon dioxide melts. The first heat exchanger 4a is maintained in the first operating mode 101.

The capture/melting cycle 81 of the third heat exchanger 4c ends at the time T5 at the switching to the first operating mode 101, while the first heat exchanger 4a switches again to the second operating mode 102 and the second heat exchanger 4b remains at the first operating mode 101. Thus, the capture process happens that way until the times T6, T7, T8 and following as long as necessary.

It shall be understood from the figure 6 that the capture/melting cycles 81 of the three heat exchangers are offset from one another by one period of use 80. Since the capture/melting cycle 81 lasts three periods of use 80 including two in the first operating mode 101 and one in the second operating mode 102, the offset of the capture/melting cycles 81 makes it possible, at each period of use 80 where the three heat exchangers are working, to always have two heat exchangers in the first operating mode 101, while the last heat exchanger is in the second operating mode 102. Thus, the carbon dioxide is optimally captured when the capture system is equipped with three heat exchangers.

Of course, the invention is not restricted to the examples above, and many refinements may be added to these examples in the framework of the invention.

The invention, as described above, reaches its goal and makes it possible to suggest a system to capture carbon dioxide from a carbon dioxide containing gas, comprising at least two exchangers that can be operated in a first operating mode where the carbon dioxide is captured, and in a second operating mode where the captured carbon dioxide is melted. Variants that are not described here could be implemented in the frame of the invention as soon as, according to the invention, they comprise a capture system according to the invention.

CLAIMS

- 1- A capture system (1) of carbon dioxide from a gas containing carbon dioxide, comprising at least a first heat exchanger (4a) and a second heat exchanger (4b), wherein each of the heat exchangers (4) comprises at least a chamber (14), a first line (12a) and a second line (12b) that both extend through the chamber (14), characterized in that the first heat exchanger (4a) and the second heat exchanger (4b) are configured to be operated in a first operating mode (101), where the chamber (14) is so configured that a carbon dioxide containing gas flow (2) flows through it and to capture by desublimation the carbon dioxide from said carbon dioxide containing gas flow (2) in order to generate a decarbonized gas flow (3), and in a second operating mode (102), wherein the carbon dioxide containing gas flow (2) flows through the first line (12a) and/or the second line (12b) to melt the carbon dioxide captured in the chamber (14), the capture system (1) comprising control means (5) configured to operate an alternation between the first operating mode (101) and the second operating mode (102).
- 2- A capture system (1) according to claim 1, wherein the control means (5) are configured to operate an alternation between a heat exchanger (4) and another one between the first operating mode (101) and the second operating mode (102).
- 3- A capture system (1) according to claim 1 or 2, wherein the control means (5) comprise at least one management means (42) configured to regulate a circulation of a first coolant that flows through either one of the lines (12) of either one of the heat exchangers (4).
- 4- A capture system (1) according to the previous claim, wherein the management means (42) comprises at least a first valve (42a) upstream from either one of the lines (12) of either one of the heat exchangers (4) and/or at least a second valve (42b) downstream from either one of the lines (12) of either one of the heat exchangers (4).
- 5- A capture system (1) according to any one of the previous claims, wherein the control means (5) comprise at least one management means (40) configured to regulate a circulation of a second coolant that flows through either one of the lines (12) of either one of the heat exchangers (4).
- 6- A capture system (1) according to the previous claim, wherein the management device (40) comprises at least a third valve (40a) upstream from either one of the lines

(12) of either one of the heat exchangers (4) and/or at least a fourth valve (40b) downstream from either one of the lines (12) of either one of the heat exchangers (4).

7- A capture system (1) according to claims 5 or 6, wherein the first coolant and/or the second coolant is the decarbonized gas flow (3).

5 **8-** A capture system (1) according to any one of claims 5 to 7, wherein the first coolant and/or the second coolant is a liquefied natural gas flow (30) or a refrigerant fluid.

9- A capture system (1) according to any one of the previous claims, wherein the control means (5) comprise at least one monitoring means (38) configured to regulate a
10 circulation of the carbon dioxide containing gas flow (2) through one or the other one of the lines (12) of either one of the heat exchangers (4).

10- A capture system (1) according to the previous claim, wherein the monitoring means (38) comprises at least a fifth valve (38a) upstream from either one of the lines (12) of either one of the heat exchangers (4) and/or at least a sixth valve (38b)
15 downstream from either one of the lines (12) of either one of the heat exchangers (4).

11- A capture system (1) according to any one of the previous claims, wherein the control means (5) comprise at least one monitoring device configured to regulate the circulation of the carbon dioxide containing gas flow (2) through either one of the heat exchangers (4) around either one of its lines (12).

20 **12-** A capture system (1) according to the previous claim, characterized in that the monitoring device comprises at least a seventh valve (44a) upstream from the chamber (14) of either one of the heat exchangers (4) and/or at least an eighth valve (44b) downstream from the chamber (14) of either one of the heat exchangers (4).

13- A capture system (1) according to any one of the previous claims, comprising a
25 first thermal exchanger (16) configured to operate an exchange of heat between the carbon dioxide containing gas flow (2) and the decarbonized gas flow (3), wherein the first thermal exchanger (16) comprises a first line (16a) through which a carbon dioxide containing gas flow (2) flows and a second line (16b) through which the decarbonized gas flow (3) flows, said first line (16a) being located upstream from the chamber (14) of
30 either one of the heat exchangers (4) and said second line (16b) being located downstream from the chamber (14).

14- A capture system (1) according to the previous claim, comprising a regulation device (61) of a temperature of the carbon dioxide containing gas flow (2) upstream from the first line (16a) of the first thermal exchanger (16), configured to regulate the temperature of the carbon dioxide containing gas flow (2) after flowing through the first line (12a) and/or the second line (12b) of either one of the heat exchangers (4), the regulation device (61) comprising a bypass line (62) of the first line (12a) and/or of the second line (12b) of either one of the heat exchangers (4), a monitoring valve (63) configured to monitor the circulation of the carbon dioxide containing gas flow (2) through the bypass line (62), and a detection means (64) of the temperature of the carbon dioxide containing gas flow (2) upstream from the first line (16a) of said thermal exchanger (16).

15- A capture system (1) according to any one of the previous claims, comprising a recovery line (31) connected to each of the heat exchangers (4) and configured to collect the liquid-state carbon dioxide from at least one of the heat exchangers (4), wherein the recovery line (31) comprises a recovery valve (19).

16- A capture system (1) according to one of the previous claims, comprising a third heat exchanger (4c) configured to be operated according to the first operating mode (101) and according to the second operating mode (102), wherein the control means (5) are configured to operate an alternation between the first operating mode (101) and the second operating mode (102) on the third heat exchanger (4c).

17- A process to capture carbon dioxide from a carbon dioxide containing gas flow (2) implemented by a capture system (1) of carbon dioxide from the carbon dioxide containing gas flow according to any one of the previous claims, wherein:

- at least one of the heat exchangers (4) is operated according to the first operating mode (101) in order to desublimize the carbon dioxide in the carbon dioxide containing gas flow (2) through the chamber (14) of said heat exchanger (4);
- an operating mode is switched from the first operating mode (101) to the second operating mode (102) of said heat exchanger (4) in order to melt the desublimized carbon dioxide in the chamber (14) by circulating the carbon dioxide containing gas flow (2) through the first line (12a) and/or through the second line (12b) of said heat exchanger (4).

18- A capture process according to the previous claim, wherein at least one of the heat exchangers (4) is in the first operating mode (101) when the other heat exchanger (4) is in the second operating mode (102).

5 **19-** A capture process according to claim 17 or 18, wherein the first operating mode (101) followed by the second operating mode (102) constitute a capture/melting cycle (81) of the carbon dioxide, said capture/melting cycle (81) being repeated by iterations.

20- A capture process according to the previous claim, implemented by a capture system (1) according to claim 16, wherein two heat exchangers (4) are in the first operating mode (101) while the last heat exchanger (4) is in the second operating mode (102), the capture/melting cycle (81) comprising three periods of use (80), with two corresponding to the first operating mode (101) and one corresponding to the second operating mode (102), the three periods of use (80) being of equal durations, the capture/melting cycle (81) being operated so that each of the three heat exchangers (4) is operated according to each of the three periods of use (80) and that there is a simultaneous transition between the periods of use (80) for the three heat exchangers (4).

21- A capture process according to any one of the claims 17 to 20, wherein a first coolant and a second coolant flow respectively through the first line (12a) and the second line (12b) of at least one of the heat exchangers (4) when it is in the first operating mode (101).

22- A capture process according to any one of the claims 17 to 21 in combination with the claims 4, 6, 10, 12 and 15, wherein the first valve (42a), the second valve (42b), the third valve (40a), the fourth valve (40b), the seventh valve (44a) and the eighth valve (44b) are open while the fifth valve (38a), the sixth valve (38b) and the recovery valve (19) are closed when the considered heat exchanger (4) is in the first operating mode (101).

23- A capture process according to any one of the claims 17 to 22 in combination with the claims 4, 6, 10, 12 and 15, wherein the first valve (42a), the second valve (42b), the third valve (40a), the fourth valve (40b), the seventh valve (44a) and the eighth valve (44b) are closed while the fifth valve (38a), the sixth valve (38b) and the recovery valve (19) are open when the considered heat exchanger (4) is in the second operating mode (102).

24- A capture process according to any one of the claims 17 to 23, implemented by a capture system (1) according to claim 14, wherein the regulation device (61) for the temperature monitors an opening section of the monitoring valve (63) in order to calculate a flowrate of the carbon dioxide containing gas flow (2) through the first line (12a) and/or the second line (12b) of the heat exchanger (4) that is in the second operating mode (102) and a flowrate of the carbon dioxide containing gas flow (2) through the bypass line (62), the opening section of the monitoring valve (63) depending on at least a temperature of the carbon dioxide containing gas flow (2) as measured by the temperature detection means (64).

25- A capture process according to any one of the claims 17 to 24, wherein the melted carbon dioxide from the heat exchanger (4) when it is in the second operating mode (102) is stored.