(54) Abstract Title: **Carbon dioxide recovery in pellets production**

(57) Recovery of carbon dioxide from carbon dioxide pellets production by compressing (5,6) and condensing (7) the carbon dioxide gas lost by the pellets production.

Compressing the gas can be in one or two steps. The first step having a plurality of compressors (5) connected in parallel, the second step having a compressor (6) serially connected to the compressors (5) of the first step.

The compressed gas is pre-cooled (9a,9b) downstream of the compressors (5) and further cooled (10a,10b) downstream of the compressor (6).

At least one of the compressors(5,6) are a hermetic, a reciprocating or a scroll type compressor. Also at least one compressor is oil lubricated.
Carbon Dioxide Recovery

Field of the Invention

The present invention relates to the recovery of carbon dioxide gas and in particular, to the recovery of carbon dioxide gas for liquifying the gas for re-use.

Background

The production of solid carbon dioxide or "dry ice" pellets from liquid carbon dioxide is well-known. European patent application published under number EP1328765 describes a device for making such pellets.

A by-product of the process for manufacturing carbon dioxide pellets is carbon dioxide gas. Unless the carbon dioxide gas is recovered, it cannot be re-used, which means that the cost of manufacturing carbon dioxide pellets is increased due to the requirement for excessive amounts of liquid carbon dioxide, approximately 50% of which is wasted in the pellet making process. Furthermore, waste carbon dioxide gas is environmentally undesirable.

There are many systems for recovering carbon dioxide gas available, for example, the RRS330A recovery system from Asco Carbon Dioxide Ltd. However, such systems are relatively expensive and structurally intricate. Consequently, it is not economically viable to use such systems in many situations.

More simple systems have been suggested for carbon dioxide recovery, including that described in EP1328765, which includes a simple combination of compressors and heat exchangers. However, such systems do not achieve effective conversion of carbon dioxide gas to carbon dioxide liquid.
Summary of the Invention

It is a general aim of the present invention to ameliorate at least some of the disadvantages of the prior art discussed above. It is a preferred aim to provide a more economical solution to the problem of carbon dioxide recovery in relatively low capacity "dry ice" production systems.

In a first aspect, the present invention provides a system for converting carbon dioxide gas to a liquid, comprising a plurality of compressors for compressing the gas and a condenser for cooling the compressed gas, wherein the plurality of compressors are connected in parallel.

The parallel arrangement of the compressors allows a corresponding increase in the volume of carbon dioxide gas compressed simultaneously without having to resort to a higher capacity compressor, which improves the overall efficiency of the system. Furthermore, the plurality of compressors provides a greater overall surface area of compression, which improves the heat dissipation in the system. It is important that the temperature be kept as low as possible, in order to avoid damage to the system components. Therefore, improved heat dissipation is desirable.

In a preferred embodiment of the invention, a further compressor is provided in the system in series with the compressors that are connected in parallel. The further compressor provides a further compression stage, which ensures that the carbon dioxide gas is adequately compressed before it enters the condenser. Usually, it is not possible to complete the compression process in a single step because the heat produced in the complete compression process is too high for the system components to withstand. Preferably, the further compressor is downstream of the compressors connected in parallel.
and operates at a higher pressure than the compressors connected in parallel.

At least one of the compressors is preferably an oil-lubricated reciprocating hermetic compressor. Alternatively, at least one of the compressors is an oil-lubricated hermetic scroll compressor. Such compressors have a low mass, are compact and are inexpensive. The hermetic feature of such compressors avoids leaks, which is also desirable.

In a further preferred embodiment of the invention a pre-cooling means, preferably a heat exchanger, is provided downstream of the compressors that are connected in parallel and upstream of the further compressor, i.e. between the two stages of compression. The pre-cooling means serve to remove heat from the carbon dioxide before compression so that excessive compression temperatures can be avoided. In a yet further preferred embodiment of the invention, a pre-cooling means is provided downstream of the further compressor and upstream of the condenser so that heat is removed from the compressed gas before condensation, which improves the efficiency of condensation and oil separation.

In a second aspect, the invention provides a combined pelletizing and carbon dioxide recovery system comprising the system of the first aspect of the invention and a pelletizer.

In a third aspect, the invention provides a method of converting carbon dioxide gas to a liquid, comprising compressing the gas and condensing the compressed gas, wherein compression of the gas is carried out in a plurality of compressors that are connected in parallel.

In a preferred embodiment of the invention, the method comprises a two-stage compression process, at least one stage being carried out in the plurality of compressors connected in parallel. Preferably, the first
stage of compression is carried out in the plurality of compressors connected in parallel and the second stage of compression is carried out in a further compressor that is downstream of the compressors connected in parallel and operates at a pressure above that of the compressors connected in parallel.

In a further preferred embodiment, the gas is cooled following compression in the plurality of compressors that are connected in parallel and prior to compression in the further compressor. In a yet further embodiment, the gas is cooled following compression and prior to condensation.

In a fourth aspect, the invention provides a method for producing carbon dioxide pellets from liquid carbon dioxide comprising using the method of the third aspect of the invention to recover excess carbon dioxide from production of the pellets.

**Brief Description of the Drawing**

Embodiments of the invention will be described, by way of example, with reference to the accompanying drawing in which:

Figure 1 is a schematic diagram of a carbon dioxide recovery system in accordance with a first embodiment of the invention.

**Description of an Embodiment**

Pelletizers which use liquid carbon dioxide to make solid carbon dioxide pellets produce carbon dioxide gas as a by-product. In fact, only about 50% of the liquid carbon dioxide is consumed in the pelletization process; the other 50% is lost as carbon dioxide gas. The system of the present invention allows that carbon dioxide gas to be
recovered and re-liquified by means of a two-stage compression and a condensation process so that it can be used again in the pelletizer.

In Figure 1, a combined pelletizing and carbon dioxide recovery system 1 has a system for recovering carbon dioxide gas 2, a pelletizer 3 and a storage unit 4 for storing liquid carbon dioxide. The pelletizer 3 will not be described in detail here but any suitable pelletizer can be used, such as the pelletizer described in EP 1328765.

The system for recovering carbon dioxide gas 2 has a pair of compressors 5 connected in parallel, which provide a first "low pressure" stage of compression. A second "high pressure" stage of compression is provided by a further compressor 6 arranged downstream of and in series with the pair of compressors 5.

All of the compressors 5,6 are oil-lubricated hermetic scroll compressors. Such compressors have a motor and a compression chamber sealed within a pressure vessel. Any of a number of suitable compressors can be used, such as the Copeland scroll compressor.

A condenser 7, which is arranged downstream of the compressor 6, contains a refrigerant, such as freon. The refrigerant has a further compression and condensing unit 8 associated with it, which is arranged in the vicinity of the condenser 7 and comprises a compressor 8a and a condenser 8b. Any of a number of suitable condensers can be used, such as the plate heat exchangers supplied by Alfa Laval.

A pre-cooling means in the form of a series of heat exchangers 9a and 9b is arranged downstream of the compressors 5 connected in parallel and upstream of the compressors 6, so that the carbon dioxide can be cooled prior to the second stage of compression. A further pre-cooling means in the form of a series of heat exchangers 10a and 10b is
provided downstream of the compressor 6 and upstream of the condenser 7. Any of a number of suitable heat exchangers can be used, such as the plate heat exchangers supplied by Alfa Laval.

In use, carbon dioxide gas that is produced by the pelletizer 3 as a result of the solidification of solid carbon dioxide, is transported to the pair of compressors 5 that are connected in parallel, where it is split between the pair of compressors. Both compressors 5 operate at substantially the same pressure, so that the carbon dioxide is drawn in equally by each compressor 5. The compressors 5 operate at a pressure of between approximately 1 and 4 bar and compress the gas to a pressure of between approximately 4 and 10 bar. This first compression stage is particularly important for reducing the volume of the gas, which tends to be relatively high as it leaves the pelletizer 3. The gas generally needs to be compressed to a degree of at least approximately 4:1.

Typically, carbon dioxide gas exits the pelletizer 3 at a temperature of between approximately −80°C and −70°C. The gas gains a degree of heat from pipework between the pelletizer 3 and the compressors 5 connected in parallel, and is thus at a temperature of between approximately −40°C and −20°C just upstream of the compressors 5.

Due to the considerable amount of heat produced as a result of compression, and also as a result of heat generated by the compressor motors, it is necessary to constantly cool the compressors 5. It is important that the heat generated is prevented from being transferred to the compressed gas, which is typically at a temperature of between 100°C and 120°C when it leaves the compressors 5.

The compressors 5 are cooled by spraying a low viscosity oil onto their internal walls at regular intervals; a constant flow of oil also serves to
cool the motor (not shown) of each compressor. In addition, the motor of each compressor 5 is cooled to an extent by the incoming flow of gas.

The splitting of the carbon dioxide gas between a number of different compressors 5 also increases the surface area over which heat dissipation takes place, with the result that the heat generated as a result of the compression of the gas can be dissipated more efficiently.

Following the "low pressure" compression stage, the compressed gas is transported to the heat exchanger 9a, which cools the gas from a temperature of between approximately 100°C and 120°C to a temperature of between approximately 30°C and 50°C, using air. Following cooling in the heat exchanger 9a, the gas is passed to the heat exchanger 9b, where it is further cooled to a temperature of between approximately 10°C and 20°C by means of a refrigerant, such as freon, before it is conveyed to the compressor 6. The reduction in temperature of the gas before compression is desirable because even small temperature increases in the gas before compression can result in excessive temperatures post-compression, due to the build up of heat as a result of the compression process.

The pressure upstream of the compressor 6 is between approximately 4 and 10 bar and the temperature is between approximately 10 and 20°C. Downstream of the compressor 6, the pressure is between approximately 12 to 25 bar and the temperature is between approximately 100°C and 120°C. Oil is also used to cool the compressor 6. Any oil that becomes mixed with the carbon dioxide gas is separated in a filter system 11 and returned to the compressor 6 for re-use.
Gas exits the compressor 6 at a pressure of between approximately 12 and 25 bar but, again, contains a significant amount of heat energy as a result of the compression. The gas is passed through the heat exchanger 10a, which uses air as a cooling medium, so that the temperature can be reduced to between approximately 30°C and 50°C before the gas passed to the heat exchanger 10b. The heat exchanger 10b uses a refrigerant to cool the gas further to a temperature of between approximately 10°C and 20°C before it enters the condenser 7. In the condenser 7, the compressed gas is cooled again by means of the refrigerant, which is supplied from the refrigerant condensing unit 8, so that it is liquified.

As the refrigerant, which is a liquid when it is delivered to the condenser 7, absorbs the heat from the compressed gas in the condenser 7, it evaporates. The gaseous refrigerant then passes the heat exchangers 9b and 10b. It is returned to the refrigerant compression and condensing unit 8 and is compressed and cooled, so that it returns to its liquid state for further use in cooling.

At the same time, the removal of heat from the compressed carbon dioxide in the condenser 7 reduces its temperature to between approximately -35°C and -20°C and results in its liquefaction. The liquid carbon dioxide is drawn out of the condenser 7 and delivered to the pelletizer 3 in order to produce further solid carbon dioxide pellets, or alternatively to the storage unit 4 for later delivery to the pelletizer 3.

It will be appreciated by a person skilled in the art that a number of modifications can be made to the embodiment of the invention described above. For example, a plurality of compressors 6 could be connected in parallel in the second stage of compression in addition to the pair of compressors 5 that are connected in parallel in the first stage, in order to further improve the overall heat dissipation of the
system but this is only likely to be necessary where the compressor 6 is running at a temperature in the region of 120°C, which is not likely to be a common occurrence. Similarly, more than two compressors 5 could be connected in parallel in the first compression stage.

It would be possible to include three or more stages of compression, the compression stages being arranged in series in a similar manner to the two stages of compression described above. Alternatively, a single compression stage may be sufficient if the compressor used were able to operate at the temperature required.

It would also be possible to replace the refrigerant in the condenser 7 with another coolant, such as air. The coolant can be selected on the basis of the required operating characteristics. Where there is more than one stage of compression and condensation, different coolants can be used in the different stages.

The compressors 5,6 do not have to be oil-lubricated hermetic scroll compressors. They are, however, preferably low cost, economic compressors. Other examples include oil-lubricated reciprocating hermetic compressors and non-lubricated open compressors, such as those manufactured by Atlas Copco.

A cooling fan could be used in conjunction with one or more of the heat exchangers 9a, 9b,10a, 10b or indeed with the condenser 7.
CLAIMS

1. A system for converting carbon dioxide gas to a liquid, comprising a plurality of compressors for compressing the gas and a condenser for condensing the compressed gas, wherein the plurality of compressors are connected in parallel.

2. A system as claimed in Claim 1, wherein a further compressor is included in the system, the further compressor being in series with the plurality of compressors connected in parallel.

3. A system as claimed in Claim 2, wherein the further compressor is downstream of the compressors connected in parallel and is adapted to operate at a pressure above that of the compressors connected in parallel.

4. A system as claimed in Claim 2 or 3, wherein a first pre-cooling means is provided downstream of the plurality of compressors connected in parallel and upstream of the further compressor.

5. A system as claimed in Claim 4, wherein a second pre-cooling means is arranged downstream of the further compressor and upstream of the condenser.

6. A system as claimed in Claim 4 or 5, wherein the first and/or second pre-cooling means is a heat exchanger.

7. A system as claimed in any one of the proceeding claims, wherein at least one of the compressors is a hermetic compressor.

8. A system as claimed in any one of the preceding claims, wherein at least one of the compressors is a reciprocating compressor.
9. A system as claimed in any one of the preceding claims, wherein at least one of the compressors is a scroll compressor.

10. A system as claimed in any one of the preceding claims, wherein at least one of the compressors is an oil-lubricated compressor.

11. A system for converting carbon dioxide gas to a liquid substantially as herein described with reference to the accompanying drawing.

12. A combined pelletizing and carbon dioxide recovery system comprising a system for converting carbon dioxide gas to a liquid, as claimed in any one of the preceding claims, and a pelletizer.

13. A combined pelletizing and carbon dioxide recovery system substantially as described herein with reference to the accompanying drawing.

14. A method of converting carbon dioxide gas to a liquid, comprising compressing the gas and condensing the compressed gas, wherein compression of the gas is carried out in a plurality of compressors that are connected in parallel.

15. A method as claimed in Claim 14, wherein the compression of the gas is carried out in two stages, at least one stage being carried out in the plurality of compressors connected in parallel.

16. A method as claimed in Claim 15, wherein the first stage of compression is carried out in the plurality of compressors connected in parallel and the second stage of compression is carried out in a further compressor that is downstream of the compressors connected in parallel and operates at a pressure above that of the compressors connected in parallel.

17. A method as claimed in any one of Claim 16, wherein the gas is cooled following compression in the plurality of compressors that are connected in parallel and prior to compression in the further compressor.
18. A method as claimed in any one of Claims 14 to 17, wherein the gas is cooled following compression and prior to condensation.

19. A method of converting carbon dioxide gas to a liquid substantially as herein described with reference to the accompanying drawing.

20. A method for producing carbon dioxide pellets from liquid carbon dioxide comprising using the method of converting carbon dioxide gas to a liquid as claimed in any one of Claims 14 to 19 to recover excess carbon dioxide from production of the pellets.

21. A method for producing carbon dioxide pellets substantially as herein described with reference to the accompanying drawing.
Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC:

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