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- [54] **PURIFICATION OF CARBON DIOXIDE**
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Related U.S. Application Data

- [63] Continuation-in-part of application No. 08/947,721, Oct. 9, 1997, Pat. No. 5,858,068.

- [51] **Int. Cl.⁷** **B01D 53/04**
- [52] **U.S. Cl.** **95/118; 95/135; 95/138; 95/141; 95/143**
- [58] **Field of Search** 95/114-118, 135-138, 95/141-143, 902, 130; 96/108, 132, 147, 148, 154

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[57] ABSTRACT

Industrial grade carbon dioxide may contain unacceptable amounts of sulfur-containing materials, oxygen, and organic materials particularly detrimental to food-related uses of carbon dioxide. These can be effectively removed by a bed of silver-exchanged faujasite and an MFI-type molecular sieve. This permits an on-site, on-demand method of purifying carbon dioxide ranging from laboratory to tank car seals.

11 Claims, 1 Drawing Sheet

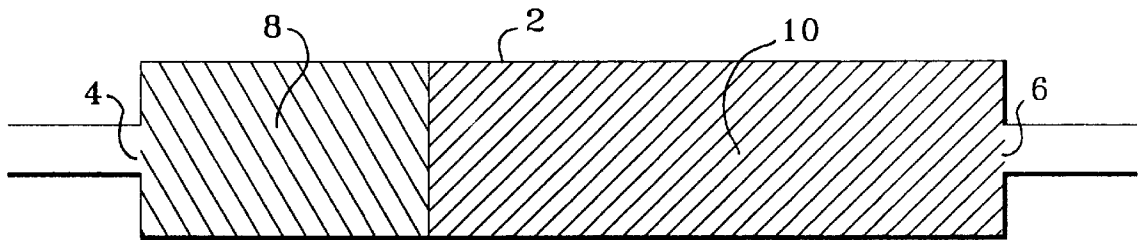


Fig.

PURIFICATION OF CARBON DIOXIDE**CROSS REFERENCE TO RELATED APPLICATION**

This application is a continuation-in-part of our copending application, application Ser. No. 08/947,721 filed Oct. 9, 1997, now U.S. Pat. No. 5,858,068, all of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Carbon dioxide has been known for centuries, with Pliny the Elder describing it in the context of poisonous vapors coming from caverns. In the seventeenth century, Van Helmont obtained carbon dioxide by such means as fermentation and acidification of carbonates, and also studied many of its properties. Later it was recognized as an acidic gas but it was not until the end of the eighteenth century that Lavoisier recognized it as a compound of carbon and oxygen of a given proportion.

Since mineral waters (solutions of carbon dioxide in water) were thought to have medicinal properties, there was from the onset an incentive to commercially exploit carbon dioxide. Faraday made liquid and solid carbon dioxide using a hydraulic pump and studied solid carbon dioxide as a refrigerant. Its uses over time has proliferated to include such diverse applications as beverage carbonation, chemical manufacture, fire fighting, food freezing, greenhouses, oil well secondary recovery, as an atmosphere in welding, and even more recently in supercritical extraction processes.

The bulk of carbon dioxide is generated from ammonia and hydrogen plants as process gas carbon dioxide resulting from the reaction between hydrocarbons and steam. The carbon dioxide produced by such methods has a high purity but may contain, inter alia traces of hydrogen sulfide, sulfur dioxide, and hydrocarbons which are particularly detrimental to its use in the food and drink industries. Since approximately 18% of the carbon dioxide produced is used for beverage carbonation, removal of these impurities from carbon dioxide is of major commercial importance. Carbon dioxide is also used in the handling and transportation of foodstuffs since the growth of bacteria can be prevented by using carbon dioxide to forestall oxidation leading to a loss of flavor. Coffee is packed under carbon dioxide, and fruits, vegetables, and cereals often are transported in an atmosphere of carbon dioxide. For all such foodstuff-related uses, the presence of contaminants which lead to an unacceptable odor or taste should be less than one milligram/kg. This application is concerned with purification of carbon dioxide for use in foodstuffs and in other areas, such as supercritical extraction and supercritical chromatography, where high purity carbon dioxide is required.

The most commonly used purification methods are treatments with potassium permanganate, potassium dichromate, or active carbon. Both potassium permanganate and potassium dichromate are active oxidizing agents, consequently scrubbing generally results in oxidation of unwanted materials. In the case of hydrogen sulfide as a contaminant, oxidation results in the formation of sulfur which is readily removed as a solid. Activated carbon has been widely used as an adsorbent for impurities from carbon dioxide. Nonetheless, the presence of residual impurities often remains a problem in providing food-grade carbon dioxide which meets the Compressed Gas Association commodity specifications or which can otherwise be used in supercritical applications. Where water is necessary to be removed from the gas, a separate drying step over alumina has sometimes been used in the past.

Although the commercial production of carbon dioxide has been ongoing for many years now, and although the purification of the gas has been the subject of many efforts, nonetheless a truly high purity carbon dioxide is expensive to process and not widely available. In particular, we have found that impurities such as water, sulfur-containing compounds, nitrogen-containing compounds, and hydrocarbons may be removed by a combination of adsorbents very effectively and very efficiently.

SUMMARY OF THE INVENTION

The invention described within is a method of purifying gaseous carbon dioxide. In particular, our invention is a process for preparing high purity carbon dioxide suitable for use in carbonated beverages, as well as other food-related applications (that is, food grade carbon dioxide) as well as a process for purifying carbon dioxide to a level suitable for use in supercritical extraction and supercritical chromatography. An embodiment comprises passing gaseous carbon dioxide through one or more beds containing silver-exchanged faujasite and a molecular sieve such as an MFI-type molecular sieve with a Si:Al ratio of at least 10, ZSM-12 and ZSM-23. In a more specific embodiment the molecular sieve is ZSM-5. In a still more specific embodiment the molecular sieve is ZSM-5 and the ratio of faujasite to ZSM-5 is about 1. Other embodiments and applications will be apparent from the ensuing description.

BRIEF DESCRIPTION OF THE DRAWING

The FIGURE is a simplified side view of the apparatus for purifying carbon dioxide. Additional pieces of apparatus that may be employed in connection with the apparatus of the invention are not shown.

DESCRIPTION OF THE INVENTION

The need for high purity carbon dioxide in food-related applications, such as in carbonated beverages as well as food storage, is well documented. Additionally, there is a need for high purity carbon dioxide in such applications as supercritical extraction and supercritical chromatography. Our invention is a process for purifying carbon dioxide to sufficient levels as to enable its use in the foregoing applications. Our purification process relies on a molecular sieve such as an MFI-type molecular sieve with a Si:Al ratio of at least 10, ZSM-12, ZSM-23, or a combination of a silver-exchanged faujasite and the molecular sieve to remove sulfur compounds, especially hydrogen sulfide, and hydrocarbons often present in industrial grade carbon dioxide at unacceptably high levels. The organic compounds may be removed to a level of less than 10 ppt in the purified carbon dioxide, and the COS to a level of less than 15 ppb in the purified carbon dioxide. The use of additional adsorbents, e.g., zeolites such as 3A, 4A and 5A, is optional but they may be employed to remove other impurities such as water where desired. Similarly, reduced metals on refractory inorganic oxide supports are optional and may be employed to remove impurities such as oxygen.

An advantage of our method is that the purification is conveniently done on-site, on demand, and is conveniently scaled from relatively small to quite large amounts of carbon dioxide. For example, one may purify small quantities of carbon dioxide for laboratory use from a tank of carbon dioxide using a cartridge containing the materials described herein affixed to the tank outlet, with carbon dioxide being purified as it is drawn from the tank. At another end of the scale, carbon dioxide may be generated, and/or stored in

large quantities on-site, then purified by passage through commensurately sized beds of adsorbent as described herein. The core advantage of our invention in both cases is that carbon dioxide is purified as and when used, which is inherently a more efficient process of purification than one which purifies the carbon dioxide long before it is used.

The preferred adsorbent which serves to purify the carbon dioxide is the combination of a silver-exchanged zeolite having a faujasite structure and an MFI-type molecular sieve, ZSM-12, or ZSM-23. The zeolite having a faujasite structure may be naturally occurring or a synthetic analog such as zeolite X and is referred to herein as a "faujasite". The faujasite may be silver exchanged to the extent of from about 5 up to about 90%. That is, from about 5 up to about 90 percent of the available sites in faujasite are exchanged with silver, which corresponds to material having 0.1–3 weight percent silver. A preferred silver-exchanged faujasite is silver-exchanged zeolite X. The molecular sieve in our adsorbent may be one of the MFI-type molecular sieves with a Si:Al ratio of at least 10 (i.e., silica:alumina is at least 20) and preferably greater than about 20 such as ZSM-5 and silicalite. The molecular sieve adsorbent may also be ZSM-12 or ZSM-23. Generally, the faujasite and molecular sieve will be used in a weight ratio from about 1:3 to about 3:1 although normally the exact ratio of components is not critical to the success of our invention. The faujasite and molecular sieve may be used as a mixture, or as a sequence of separate beds. We have found that molecular sieves with a pore diameter in the 4–6 angstrom range are especially suitable in the practice of our invention. It is possible to use solely the MFI-type molecular sieve and still at least partially purify the carbon dioxide. A higher degree of purity is achieved with the above-described combination, but in applications where a greater concentration of impurities is acceptable the MFI-type molecular sieve may be used without the silver-exchanged faujasite. Therefore, depending upon the application and the desired level of purity of the carbon dioxide, the MFI-type molecular sieve may be used alone or in combination with the silver-exchanged faujasite. Similarly, it is contemplated that the ZSM-12 or ZSM-23 or a mixture thereof may be used independently of the silver-exchanged faujasite to at least partially purify the carbon dioxide.

The foregoing adsorbents are well suited for the removal of sulfur-containing compounds, especially hydrogen sulfide, nitrogen-containing compounds, and hydrocarbons which are likely to be found as impurities in gaseous carbon dioxide. As a class of hydrocarbons, alcohols are readily removed by the above-described mixture of adsorbents. We also have found that zeolites such as 3A, 4A, and 5A also may be used optionally as a prebed, especially to remove other impurities such as water. Whether other zeolites or molecular sieves are used in combination with the above-described faujasite-molecular sieve adsorbent is largely a matter of choice and depends mainly upon the nature of the impurities to be removed from the carbon dioxide stream. When zeolites such as 3A, 4A, and 5A are employed in the present invention, it is preferred to position a bed of the 3A, 4A, and/or 5A zeolite so that the carbon dioxide passes through the 3A, 4A, and/or 5A zeolite prior to passing through any other adsorbent thereby preventing other adsorbents from needless contact with moisture.

Similarly, reduced metals, i.e., metals in the zero valent state, supported on a matrix material may be optionally employed to remove impurities such as oxygen to levels as low as, for example, less than 1 ppm oxygen. Preferred reduced metals include nickel and copper, with the most

preferred being copper. Matrix materials may be a high surface area refractory inorganic oxide such as those commonly known in the art including silicas, aluminas, and zeolites. The silicas may be amorphous or crystalline, and examples of aluminas include gamma, theta, and delta. The preferred matrix material is alumina. Such matrix materials are well known to one skilled in the art and are not discussed in detail here; for reference see U.S. Pat. No. 5,659,099 hereby incorporated by reference. The reduced metal may be impregnated so as to result in a composite having from about 0.1 weight % to about 20 weight %, and preferably from about 0.1 weight % to about 10 weight %, of the metal deposited with high dispersion and even distribution throughout the matrix material, with the weight percent of reduced metal being measured as a percent of the composite. The reduced metal and matrix material may be composited with or without a binder to form particle shapes known to those skilled in the art such as spheres, extrudates, rods, pills, pellets, tablets, or granules. Spherical particles may be formed directly by the oil-drop method or from extrudates by rolling extrudate particles on a spinning disk. The reduced metal and matrix material may be a separate bed, or may be mixed with any of the above-described adsorbents. When a silver-exchanged faujasite and a molecular sieve are used as two layers or beds, it is preferred that the reduced metal and matrix material be positioned between the silver-exchanged faujasite and the molecular sieve.

Our invention is carried out in a relatively uncomplicated way, merely by passing a stream of gaseous carbon dioxide through one or more beds of adsorbent. One may use only a single bed of a mixture of adsorbents, a bed containing different adsorbents in layers, or one can use more than one bed, each of a particular adsorbent. It is also possible to practice our invention using some combination of the foregoing. Which method is chosen is largely a matter of choice and the success of our invention is generally not dependent thereon. The resultant purified carbon dioxide is depleted in impurities such as water, oxygen, sulfur-containing compounds, nitrogen-containing compounds, alcohols and hydrocarbons. That is, the concentration of impurities in the resultant purified carbon dioxide is less than in that of the carbon dioxide before being purified by the present invention.

Turning to the Figure, the apparatus of the invention is shown as a vessel **2** having a gas fluid inlet **4** and a gas fluid outlet **6**. The vessel may be constructed of any suitable material able to conduct carbon dioxide at the flow rate and pressure of the particular application. The gas fluid inlet and outlet may further be equipped with connectors so that the apparatus may be readily placed in a flowing carbon dioxide stream. Furthermore, the gas fluid inlet and outlet may contain a retainer to prevent the solid contents of the vessel from being removed from the vessel. One bed of silver-exchanged faujasite and an MFI-type molecular sieve with a Si:Al ratio greater than about 10, where the faujasite and said sieve are in a proportion from about 1:3 to about 3:1 is shown as bed **10** in the Figure. The Figure also contains the optional bed **8** containing one or more of zeolites 3A, 4A, and 5A.

The following example is merely illustrative of our invention and is not intended to limit it in any way.

EXAMPLE

The carbon dioxide used was specified to contain less than 100 ppm total non-condensables (oxygen, nitrogen, and methane) with moisture in the 10–50 ppm range and oxygen

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up to 20 ppm. The gas also contained amounts of organic greases, e.g., a perfluoropolyether and chlorotrifluoroethane, at levels of 1–10 ppm. The gas was passed through a bed of 500 mL of a 1:1 mixture of silver-exchanged faujasite and ZSM-5 to afford a purified carbon dioxide containing less than 1 ppm each of water and oxygen, and less than 10 parts per trillion of organic materials.

In another test carbon dioxide containing 11.2 ppm of carbonyl sulfide, COS, was passed through a bed similar to the one described above. Carbonyl sulfide was used as representative of sulfur compounds to be removed from carbon dioxide. No detectable sulfur was present under conditions where the limit of detection was 1 part per billion.

The foregoing tests demonstrate the capability of our invention to remove sulfur compounds, organic materials, and water from a carbon dioxide stream to afford high purity carbon dioxide.

What is claimed is:

1. A method of purifying gaseous carbon dioxide comprising passing a stream of carbon dioxide through a silver-exchanged faujasite and a molecular sieve selected from the group consisting of an MFI-type molecular sieve with a Si:Al ratio greater than about 10, ZSM-12 and ZSM-23 where said faujasite and said sieve are in a proportion from about 1:3 to about 3:1, and recovering purified carbon dioxide having no more than 15 ppb COS and 10 ppt organic materials.

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2. The method of claim 1 wherein the Si:Al ratio of said MFI-type molecular sieve is greater than about 20.

3. The method of claim 1 wherein said MFI-type molecular sieve is selected from the group consisting of ZSM-5 and silicalite.

4. The method of claim 1 wherein the silver-exchanged faujasite is silver-exchanged zeolite X.

5. The method of claim 1 further characterized in that said carbon dioxide is additionally passed through one or more of zeolites 3A, 4A, and 5A.

6. The method of claim 5 further comprising the purified carbon dioxide additionally depleted in water.

7. The method of claim 1 further characterized in that said carbon dioxide is additionally passed through a reduced metal on a matrix material.

8. The method of claim 7 further comprising the purified carbon dioxide additionally depleted in oxygen.

9. The method of claim 7 wherein the purified carbon dioxide has less than 1 ppm oxygen.

10. The method of claim 7 wherein the reduced metal is nickel or copper and the matrix material is a refractory inorganic oxide.

11. The method of claim 1 wherein from about 5 up to about 90 percent of the available sites on faujasite are exchanged with silver.

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