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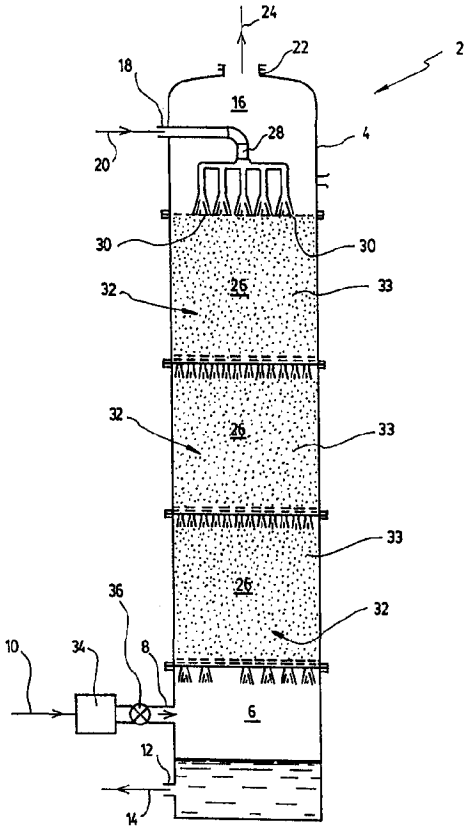
(54) Title: PROCESS AND APPARATUS FOR THE TREATMENT OF CARBON DIOXIDE WITH CARBONIC ANHYDRASE

(57) Abstract

A process is disclosed for the extraction, production and purification of carbon dioxide gas. The process may also be employed for the production of aqueous and/or organic solutions of bicarbonate ions using a precursor feed stream of gas containing carbon dioxide. The process consists of the countercurrent flushing of a packed tower-type bioreactor with gas containing carbon dioxide and a liquid solvent. The bioreactor contains carbonic anhydrase covalently bound to an inert inorganic support. The carbon dioxide of the gaseous phase diffuses into the liquid phase. The immobilized carbonic anhydrase catalyses the hydration of the carbon dioxide which forms hydrogen and bicarbonate ions. The solution of ions may be employed directly or, alternatively, subjected to an ion-exchange resin to immobilize the bicarbonate ions. The aqueous solution of hydrogen and bicarbonate ions may also be recirculated into a second identical bioreactor, wherein they are catalytically converted to water and carbon dioxide.



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PROCESS AND APPARATUS FOR THE TREATMENT OF CARBON DIOXIDE WITH CARBONIC ANHYDRASE

FIELD OF THE INVENTION

The present invention relates generally to a process for the extraction, production and purification of carbon dioxide gas. More particularly, it relates to the use of a biological molecule, namely carbonic anhydrase, to effect the reversible hydration of carbon dioxide. Carbonic anhydrase can be used for the production, purification of carbon dioxide and the products of the hydration reaction, hydrogen and bicarbonate ions. Specifically, the invention relates to a process whereby immobilized carbonic anhydrase contained within a reactor device catalyses the reversible hydration of carbon dioxide. The invention also relates to an apparatus for performing the process. The process may be employed for the production of hydrogen and bicarbonate ions.

BACKGROUND OF THE INVENTION

Carbonic anhydrase (EC 4.2.1.1.) is a globular zinc metalloenzyme of molecular mass 30,000. The enzyme was discovered in 1933 and has been the subject of intense scientific investigation. Multiple isoforms have been discovered in plant and animal tissues. The enzyme also exists in plant tissues where it is believed to facilitate the transport of carbon dioxide. Red blood cells contain isoenzymes I and II, which are the most active. Carbonic anhydrase II has the highest molecular turnover number of any known enzyme. One molecule of carbonic anhydrase can hydrate 36,000,000 molecules of carbon dioxide in a period of 60 seconds. Physiologically, carbonic anhydrase facilitates the removal of carbon dioxide from the mammalian body. The general enzyme reaction is shown below in equation 1.

Equation 1:

$$CO_2 + H_2O \Leftrightarrow H^+ + HCO_3^-$$

It is now generally accepted that the reaction occurs as two half reactions shown below in equations 2 and 3.

Equation 2:

$$E - Zn - H_2O \Leftrightarrow E - Zn - OH^- + H^+$$

Equation 3:

$$E - Zn - OH^- + CO_2 \Leftrightarrow E - Zn - HCO_3^- + H^+ \Leftarrow (+H_2O, -H_2O) \Rightarrow E - H_2O + HCO_3^-$$

Carbonic anhydrase has been used in many studies directed at improving or testing of various methods of protein immobilization. The high molecular turnover rate of the enzyme renders it an ideal protein for these types of experiments.

The presence of carbonic anhydrase in solution facilitates the transfer of carbon dioxide from the gas to the liquid phase. This effect is based on the well established laws governing the mass transfer of gases.

The management of carbon dioxide has begun to attract the attention of the scientific community, due primarily to the problem of global warming. Previous interest in carbon dioxide has been centered around the use of the gas in a variety of industrial processes. None of the currently employed carbon dioxide management systems involve enzymatic conversion of the gas and are therefore not relevant to the present application. Prior art processes for the management of carbon dioxide are described in the following US documents: 3,659,400; 3,853,712; 4,032,616; 4,047,894; 4,162,298; 4,452,676; 4,521,387; 4,710,362; 5,061,455; 5,112,740; 5,609,838; 5,618,506; 5,624,812; 5,665,319; 5,674,463; and 5,690,099.

Moreover, the United States Air Force carried out two investigations in 1965 and 1966 on the possible use of carbonic anhydrase to remove carbon dioxide from

space vehicles. The first study explored the absorption of carbon dioxide from an air stream using a closed air loop apparatus. A variety of chemicals alone and/or in combination with CA were evaluated, with respect to their capacity to remove carbon dioxide. The principal conclusion drawn was that the closed air loop system provided an adequate method to study the removal of carbon dioxide from a stream of air. The second study was directed at determining the efficiency of carbon dioxide removal from an air stream using carbonic anhydrase in the presence of various amines. The conclusion reached was that enzymatic amine solutions could possibly be used for carbon dioxide absorption and desorption in atmosphere control concepts.

Although many studies relating to the management of carbon dioxide have been conducted in prior art, there is still presently a need for a process and an apparatus that will efficaciously manage carbon dioxide rapidly and at a relatively low cost either for producing carbon dioxide or removing it from a CO_2-containing gas.

SUMMARY OF THE INVENTION

An object of the present invention is to propose a process and an apparatus that will satisfy these needs.

In accordance with the present invention, that object is achieved with a process for removing CO_2 from a CO_2-containing gas, characterized in that it comprises the step of:

a) contacting the CO_2-containing gas with an aqueous liquid, preferably water, in a bioreactor containing immobilized carbonic anhydrase, or an analog thereof, the carbonic anhydrase catalysing the hydration of the CO_2 into hydrogen ions and bicarbonate ions.

Preferably, prior to step a), there is a step of immobilizing carbonic anhydrase in the bioreactor. The step of immobilizing carbonic anhydrase in the bioreactor may comprise the step of covalently binding carbonic anhydrase to an inert solid support material mounted in the bioreactor. The step a) of contacting the CO_2-containing gas with an aqueous liquid comprises the steps of directing a stream of the CO_2-containing gas upwards into the bioreactor and directing a stream of the aqueous

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