(54) Title: SEPARATING CARBON DIOXIDE FROM AIR

(57) Abstract: Separating carbon dioxide from air by a graphene filter adapted to block oxygen and nitrogen molecules, but allow carbon dioxide molecules to pass through.
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, SL, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TN, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, — with international search report (Art. 21(3))
Separating Carbon Dioxide from Air

This invention is concerned with separating carbon dioxide from air.

Atmospheric air comprises mainly nitrogen and oxygen, with smaller amounts of argon (9,300 parts per million or ppm) and carbon dioxide (400 ppm).

Carbon dioxide is of interest in connection with climate change, being a 'greenhouse gas', thought by scientists to give rise to global warming, which may have catastrophic global effects.

It has been proposed to recover carbon dioxide from flue gases, which is expensive, in order to sequester it in various ways to prevent it entering the atmosphere. However, it has also been proposed to recover it from the atmosphere. Klaus Lackner of the University of Columbia in New York and David Keith of the University of Calgary in Canada have both proposed ways of inexpensively recovering carbon dioxide direct from the atmosphere, Lackner by absorbing the gas in plastic sheets from which it is later recovered, Keith using chemical methods.

While carbon dioxide recovered in those ways has been proposed for use in the synthesis of hydrocarbons, particularly fuels, which would reduce reliance on fossil fuels, they were devised, and appear best suited to, recovery for sequestration.

The invention provides another way to recover atmospheric carbon dioxide, more suited to reprocessing carbon dioxide into synthetic hydrocarbons.

The invention comprises separating carbon dioxide from air by a graphene filter adapted to block oxygen and nitrogen molecules, but allow carbon dioxide molecules to pass through.

Of particular importance is the separation of carbon dioxide from atmospheric air at a place where the carbon dioxide can be used, avoiding storage and transportation costs. One such place is at the site of a reactor in which the carbon dioxide is processed with hydrogen to make hydrocarbons.

The filter can be a graphene or graphene oxide sheet with defects, which may be a monolayer or may be a few layers thick. A monolayer of any size will not be self-supporting, but may be supported e.g. on a mesh substrate. A regular graphene sheet may be substantially impervious, but defects may be introduced by heating, nanoscale etching or by treatment with an acid to break carbon-carbon bonds. This has been proposed as a way of separating carbon dioxide from flue gas, which comprises mainly carbon dioxide and nitrogen, and from natural gas or landfill gas to leave just combustible methane, where the proportion of carbon dioxide is much higher than it is in the atmosphere.
Although carbon dioxide has a substantially higher molecular weight than oxygen or nitrogen, at 44 compared to 28 for N₂ and 32 for O₂, the carbon dioxide molecule is linear and centrosymmetric, so that, in one direction, it has a smaller cross-section than either oxygen or nitrogen molecules, and can pass through graphene defects that block the more abundant gases.

The graphene filter may be cylindrical, the air being passed through from one end to the other. The object is to extract as much carbon dioxide per unit time as possible from the air, rather than to extract as much as possible from a given volume of air, and so fresh air is continuously drawn in at one end, rather than air being recirculated, as less carbon dioxide will be extracted from a second pass because it will have a lower carbon dioxide content.

However, where defects cannot be precisely sized, some oxygen or nitrogen molecules may pass through with the carbon dioxide, and the carbon dioxide rich gas may be sent through a second or third filter.

Carbon dioxide molecules are significantly heavier than oxygen and nitrogen molecules, and, if the airstream is rotated, carbon dioxide molecules will preferentially move to the outside of the flow and increase the rate at which they are harvested. The airstream may be rotated by a vaned fan arrangement.

And the faster they are moving, the more rapidly will they pass through. Since the root mean square velocity of the molecules is proportional to the square root of the absolute temperature, heating the air will also increase the yield of carbon dioxide - heating to 540°K should increase yield by around 40%. Likewise, increasing pressure should also increase yield, and increasing pressure adiabatically can also increase temperature.

The invention also comprises apparatus for separating carbon dioxide from air comprising a graphene filter adapted to block oxygen and nitrogen molecules, but allow carbon dioxide molecules to pass through.

The filter may be cylindrical and located in a chamber having an inlet and an outlet at opposite ends of the cylindrical filter, the inlet having means to flow air through the chamber, and a carbon dioxide collection space in the chamber outside the filter.

The means to flow air may rotate the air flow, and may comprise a vaned fan.

The outlet end of the chamber may be constricted whereby to compress the air in the chamber.

Separating carbon dioxide from air and apparatus therefor according to the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic representation of a small area of a graphene filter;
The drawings illustrate a diagrammatic illustration of apparatus; and

Figure 3 is a process diagram.

5 The drawings illustrate comprises separating carbon dioxide from air by a graphene filter 11 adapted to block oxygen and nitrogen molecules, but allow carbon dioxide molecules to pass through.

Graphene is a monolayer, or, more realistically, multiple layers, of carbon atoms 12 in a hexagonal network. It is essentially impervious to gases, on account of electron clouds blocking the interatomic spaces 13. However, by introducing defects 14 in the network, that are large enough to allow carbon dioxide molecules to pass, while small enough to block other molecules. A monolayer will not be self-sustaining, but may be supported e.g. on a mesh substrate. However, multilayer graphene sheets will be more viable.

10 Defects 14 can be introduced by nanoscale etching or by reacting with an acid to break some carbon-carbon bonds.

Figure 1 illustrates a filter apparatus 21 in which the graphene or graphene oxide filter 11 is cylindrical, the air being passed through from one, inlet end 21a to the other, outlet end 21b. The object is to extract as much carbon dioxide per unit time as possible from the air, rather than to extract as much as possible from a given volume of air, and so fresh air is continuously drawn in at one end, rather than air being recirculated, as less carbon dioxide will be extracted from a second pass because it will have a lower carbon dioxide content. Carbon dioxide molecules passing through the filter 11 are contained between the filter 11 and a jacket 22, from which they are harvested through an outlet 23.

However, where defects cannot be precisely sized, some oxygen or nitrogen molecules may pass through with the carbon dioxide, and the carbon dioxide rich gas can be sent through a second or third filter.

Carbon dioxide molecules are significantly heavier than oxygen and nitrogen molecules, and, if the airstream is rotated, carbon dioxide molecules will preferentially move to the outside of the flow and increase the rate at which they are harvested. The airstream is generated and rotated by a vaned fan arrangement 25.

And the faster they are moving, the more rapidly will they pass through. Since the root mean square velocity of the molecules is proportional to the square root of the absolute temperature, heating the air will also increase the yield of carbon dioxide - heating to 540°K should increase yield by around 40%. Likewise, increasing pressure should also increase yield, and increasing pressure adiabatically can also increase temperature.

To this end, the outlet end 21b from the filter 11 has a restriction 26.

Figure 3 illustrates the filter 11 delivering carbon dioxide to a reactor 32 supplied with hydrogen from a source 31. The reactor, which may be a Fischer Tropsch type reactor,
reforms, using hydrogen, the carbon dioxide to carbon monoxide and mixes this with further hydrogen under heat and pressure to synthesis hydrocarbons delivered to a storage tank 33. The reactor may however, be a reactor that mixes water - the supply of hydrogen from source 31 - with carbon dioxide, dissociating both, and synthesising hydrocarbons.
Claims:

1. Separating carbon dioxide from air by a graphene filter adapted to block oxygen and nitrogen molecules, but allow carbon dioxide molecules to pass through.

2. Separation according to claim 1, at a place where the carbon dioxide can be used, avoiding storage and transportation costs.

3. Separation according to claim 2, at the site of a reactor in which the carbon dioxide is processed with hydrogen to make hydrocarbons.

4. Separation according to any one of claims 1 to 3, in which the filter is a graphene or graphene oxide sheet with defects.

5. Separation according to claim 4, in which the sheet is a monolayer.

6. Separation according to claim 4, in which the sheet is more than one layer thick, so as to be self-supporting.

7. Separation according to any one of claims 1 to 6, in which the graphene filter is cylindrical, the air being passed through from one end to the other.

8. Separation according to claim 7, in which fresh air is continuously drawn in at one end, rather than air being recirculated.

9. Separation according to any one of claims 1 to 8, in which the carbon dioxide rich gas is sent through a second or third filter.

10. Separation according to claim 7 or claim 8, in which the airstream rotated by a vaned fan arrangement.

11. Separation according to any one of claims 1 to 10, in which the air is heated.

12. Separation according to claim 11, in which the air is heated to 540°K.

13. Apparatus for separating carbon dioxide from air comprising a graphene filter adapted to block oxygen and nitrogen molecules, but allow carbon dioxide molecules to pass through.

14. Apparatus according to claim 13, in which the filter is cylindrical and located in a chamber having an inlet and an outlet at opposite ends of the cylindrical filter, the inlet having means to flow air through the chamber, and a carbon dioxide collection space in the chamber outside the filter.

15. Apparatus according to claim 14, in which the means to flow air rotate the air flow.
Apparatus according to claim 15, comprise a vaned fan.

Apparatus according to any one of claims 14 to 16, in which the outlet end of the filter is restricted whereby to compress the air.
**A. CLASSIFICATION OF SUBJECT MATTER**

INV. B01D53/22  B01D63/06  B01D71/02  C01B31/04

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

B01D  C01B

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

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

EPO-Internal , WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<tr>
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<td>paragraphs [0002], [0004], [0009], [0014] - [0017], [0024] - [0042] figures 1-3</td>
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<td>X</td>
<td>HONGJUN LIU ET AL: &quot;Insights into C02/N2 separation through nanoporous graphene from molecular dynamics&quot;, NANO SCALE, vol. 5, no. 20, 1 August 2013 (2013-08-01) pages 9984-9987, XP055212854, ISSN: 2040-3364, DOI: 10.1039/c3nr02852f</td>
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