

Claims

1. An apparatus for the production of carbon nanotubes and hydrogen from a pyrolysis gas, the apparatus comprising:

a sorbent reactor portion comprising:

a first reaction vessel having an inlet configured to accept a pyrolysis gas from a pyrolysis gas source and an outlet;

a solid sorbent and/or a solid sorbent precursor, where the solid sorbent is suitable to adsorb CO₂ from a pyrolysis gas situated within the first reaction vessel, such that a pyrolysis gas passes over the sorbent in its passage from the inlet to the outlet; and

a heating means or apparatus suitable to provide and maintain a temperature of greater than 100 °C within the first reaction vessel;

a liquid trapping means or apparatus attached to the outlet of the sorbent reactor portion;

a chemical vapour deposition reactor portion comprising:

a second reaction vessel having an inlet configured to accept a pyrolysis gas that has passed through the liquid trapping means or apparatus and an outlet;

a catalyst suitable to convert at least a portion of the pyrolysis gas into carbon nanotubes and hydrogen gas situated within the reaction vessel, such that a pyrolysis gas passes over the catalyst in its passage from the inlet to the outlet; and

a heating means or apparatus suitable to provide and maintain a temperature of greater than 100 °C within the second reaction vessel.

2. The apparatus according to Claim 1, wherein the apparatus further comprises a pyrolysis gas source, optionally wherein the pyrolysis gas source is selected from one or more of the group selected from a pyrolyser, a pyrolyser in fluid communication with an upgrader, and a storage device comprising a pyrolysed gas.

3. The apparatus according to any one of the preceding claims, wherein:

(ai) the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas is selected from one or more of the group consisting of CaO, MgO, Ca(OH)₂, Mg(OH)₂, a serpentinite mineral, magnesium silicate hydroxide, (Mg,Fe)₂SiO₄ (olivine), a molecular sieve suitable to adsorb CO₂, a metal organic framework suitable to adsorb CO₂, and activated carbon; and/or

(aii) the solid sorbent precursor is selected from one or more of the group consisting of CaCO₃, and MgCO₃, and CaMg(CO₃)₂ (dolomite); and/or

(aiii) the solid sorbent suitable to adsorb CO₂ and the solid sorbent precursor are present in the sorbent reactor portion.

4. The apparatus according to Claim 3, wherein one or both of the following apply:

(a) the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas is in one or more of a particulate form, a pelletized form and a granulated form; and

(b) the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas comprises CaO, optionally wherein:

(bi) the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas further comprises Ca(OH)₂; and/or

(bii) the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas further comprises CaCO₃; and/or

(biii) the solid sorbent is in particulate form and has a particle size of from 1 to 5 mm.

5. The apparatus according to any one of the preceding claims, wherein one or both of the following apply:

(a) the liquid trapping means or apparatus comprises a condenser and moisture trap; and

(b) the catalyst suitable to convert at least a portion of the pyrolysis gas into carbon nanotubes and hydrogen gas comprises one or more elements selected from the group consisting of Fe, Ni, Co, Mo, W, Al, Si, C and Mg, optionally wherein the catalyst suitable to convert at least a portion of the pyrolysis gas into carbon nanotubes and hydrogen gas is selected from one or more of the groups consisting of:

Fe₂O₃ and Al₂O₃ (e.g. 20 wt.% Fe₂O₃ and 80 wt.% Al₂O₃); and

Co, Mo and MgO (e.g. 40 wt.% Co, 10 wt.% Mo and 50 wt.% MgO or 3 wt.% Co, 2 wt.% Mo and 95 wt.% MgO), optionally wherein the catalyst suitable to convert at least a portion of the pyrolysis gas into carbon nanotubes and hydrogen gas is selected from one or more of the groups consisting of 40 wt.% Co, 10 wt.% Mo and 50 wt.% MgO or 3 wt.% Co, 2 wt.% Mo and 95 wt.% MgO, more optionally wherein the catalyst is 40 wt.% Co, 10 wt.% Mo and 50 wt.% MgO.

6. The apparatus according to any one of the preceding claims, wherein one or more of the following apply:

(a) the heating means or apparatus suitable to provide and maintain a temperature of greater than 100 °C within the first reaction vessel and the heating means or apparatus suitable to provide and maintain a temperature of greater than 100 °C within the second reaction vessel is an electric heater;

(b) the heating means or apparatus suitable to provide and maintain a temperature of greater than 100 °C within the first reaction vessel and the heating means or apparatus suitable to provide and maintain a temperature of greater than 100 °C within the second reaction vessel generate a temperature from 150 to 1,000 °C, such as from 400 to 700 °C, such as about 600 °C; and

(c) the pyrolysis gas is a gas obtained from a carbonaceous feedstock, optionally wherein the pyrolysis gas is obtained from one or more of the group consisting of municipal sewage sludge, plastics, biomass, and refuse derived fuel obtained from combustible components of municipal waste.

7. Use of an apparatus according to any one of Claims 1 to 6 in the production of carbon nanotubes and hydrogen from a pyrolysis gas.

8. A method of producing carbon nanotubes and hydrogen gas from a pyrolysis gas, comprising the steps of:

(a) passing a pyrolysis gas through a first reactor zone having a temperature of greater than 100 °C that houses a solid sorbent suitable for adsorbing CO₂, where a portion of the pyrolysis gas is adsorbed by the sorbent to produce an intermediate gas; and

(b) passing the intermediate gas through a second reactor zone having a temperature of greater than 100 °C that houses a catalyst, where the catalyst converts at least a portion of the intermediate gas into carbon nanotubes and hydrogen gas.

9. The method according to Claim 8, wherein the pyrolysis gas is obtained from a carbonaceous feedstock supplied by one or more of the group selected from a pyrolyser, a pyrolyser in fluid communication with an upgrader, and a storage device comprising a pyrolysed gas, optionally wherein the carbonaceous feedstock is a plastic and/or biomass, optionally wherein the carbonaceous feedstock is obtained from one or more of the group consisting of municipal sewage sludge and, more particularly, plastics, biomass, and refuse derived fuel obtained from combustible components of municipal waste.

10. The method according to Claim 8 or Claim 9, wherein: the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas is selected from one or more of the group consisting of CaO, MgO, Ca(OH)₂, Mg(OH)₂, a serpentinite mineral, magnesium silicate hydroxide, (Mg,Fe)₂SiO₄ (olivine), a molecular sieve suitable to adsorb CO₂, a metal organic framework suitable to adsorb CO₂, and activated carbon.

11. The method according to any one of Claims 8 to 10, wherein the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas is generated from a solid sorbent precursor that is selected from one or more of the group consisting of CaCO₃, and MgCO₃ and CaMg(CO₃)₂ (dolomite) prior to step (a) of Claim 8 by calcination of the solid sorbent precursor.

12. The method according to Claim 10 or Claim 11, wherein the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas is in one or more of a particulate form, a pelletized form and a granulated form, optionally wherein the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas comprises CaO, further optionally wherein:

(ci) the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas further comprises Ca(OH)₂; and/or

(cii) the solid sorbent suitable to adsorb CO₂ from a pyrolysis gas further comprises CaCO₃; and/or

(ciii) the solid sorbent is in particulate form and has a particle size of from 1 to 5 mm.

13. The method according to any one of Claims 8 to 12, wherein the method further comprises a step (di) of trapping any liquid generated in step (a) before conducting step (b) of the method according to Claim 8, optionally wherein step (di) is accomplished using a liquid trapping means or apparatus, optionally wherein the liquid trapping means or apparatus comprises a condenser and moisture trap.

14. The method according to any one of Claims 8 to 13, wherein the catalyst suitable to convert at least a portion of the pyrolysis gas into carbon nanotubes and hydrogen gas is selected from one or more of the group consisting of:

Fe₂O₃ and Al₂O₃ (e.g. 20 wt.% Fe₂O₃ and 80 wt.% Al₂O₃); and

Co, Mo and MgO (e.g. 40 wt.% Co, 10 wt.% Mo and 50 wt.% MgO or 3 wt.% Co, 2 wt.% Mo and 95 wt.% MgO), optionally wherein the catalyst suitable to convert at least a portion of the pyrolysis gas into carbon nanotubes and hydrogen gas comprises one or more elements selected from the group consisting of Fe, Ni, Co, Mo, W, Al, Si, C and Mg,

further optionally wherein the catalyst suitable to convert at least a portion of the pyrolysis gas into carbon nanotubes and hydrogen gas is selected from one or more of the groups consisting of:

Fe₂O₃ and Al₂O₃ (e.g. 20 wt.% Fe₂O₃ and 80 wt.% Al₂O₃); and

Co, Mo and MgO (e.g. 40 wt.% Co, 10 wt.% Mo and 50 wt.% MgO or 3 wt.% Co, 2 wt.% Mo and 95 wt.% MgO).

15. The method according to any one of Claims 8 to 14, wherein the temperature in the first reactor zone and/or the temperature in the second reactor zone is from 150 to 1,000 °C, such as from 400 to 700 °C, such as about 600 °C.