CLAIMS

What is claimed is:

1. A reactor system for the production of carbon allotropes, comprising a hybrid reactor configured to form carbon allotropes from a reactant gas mixture in a Bosch reaction, wherein the hybrid reactor comprises at least two distinct zones that perform different functions comprising reaction, attrition, catalyst separation, or gas separation.

2. The system of claim 1, wherein the hybrid reactor comprises:

a first zone comprising a fluidized bed disposed in a narrow portion of a reactor vessel; and

a second zone comprising an expanded area bed disposed in a wider portion of the reactor vessel, wherein a reactant gas stream in the reactor flows from the narrow fluidized bed to the wider fluidized bed.

3. The system of claim 2, wherein the expanded area bed is configured to slow the reactant gas stream to allow catalyst particles to fall back into the fluidized bed.

4. The system of claim 1, wherein the hybrid reactor comprises:

a first zone comprising a fluidized bed reactor; and

a second zone comprising a transport reactor, wherein the transport reactor is configured to circulated a portion of the material from the fluidized bed reactor to an opposite end of the fluidized bed reactor.

5. The system of claim 4, comprising dividing a reactant gas stream into portions, wherein a first portion of the reactant gas stream is injected into the fluidized bed to maintain fluidization, and a second portion of the reactant gas stream is injected into the transport reactor to push material through the transport reactor.

6. The system of claim 1, wherein the hybrid reactor comprises:
a first zone comprising a packed bed; and
a second zone comprising an expanded bed area, wherein a reactant gas stream flows through the packed bed before flowing through the expanded bed area.

7. The system of claim 6, wherein the reactant gas stream is intermittently pulsed to fluidize the packed bed.

8. The system of claim 6, wherein the expanded area bed is configured to slow the reactant gas stream to allow catalyst particles to fall back into the packed bed.

9. The system of claim 1, wherein the hybrid reactor comprises:
a first zone comprising a spouted bed;
a second zone comprising a disengaging section configured to allow catalyst particles to drop back to the spouted bed; and
a third zone comprising an expanded bed area, wherein the expanded bed area is configured to slow a reactant gas flow and allow smaller particles to fall back to the spouted bed.

10. The system of claim 1, wherein the hybrid reactor comprises:
a first zone comprising a packed bed disposed in an outer annulus of the hybrid reactor; and
a second zone comprising a fluidized bed disposed in an inner annulus of the hybrid reactor.

11. The system of claim 10, wherein a reactant gas flows through the packed bed and then into the fluidized bed.

12. The system of claim 10, wherein a material in the packed bed flows out of the bottom of the hybrid reactor into a high velocity stream of reactant gas, and wherein the high velocity stream of reactant gas recirculates the material to the top of the hybrid reactor.

13. The system of claim 11, wherein fresh catalyst is fed into the high velocity stream of reactant gas.

14. The system of claim 1, wherein the hybrid reactor comprises:

a first reactor comprising:

a first zone comprising a packed bed; and

a second zone comprising a separation zone, wherein the separation zone is configured to remove a gas from the packed bed; and

a second reactor comprising a third zone comprising a fluidized bed, wherein material from the packed bed of the first reactor flows into the fluidized bed of the second reactor.

15. The system of claim 14, wherein the fluidized bed attrits carbon allotropes from the material.

16. The system of claim 1, comprising a catalyst separation cyclone configured to remove catalyst particles from an effluent stream from the hybrid reactor and return the catalyst particles to the hybrid reactor.

17. The system of claim 1, comprising a fresh catalyst feed system configured to provide fresh catalyst to a reaction zone in the hybrid reactor.

18. The system of claim 1, comprising a spent catalyst removal system configured to remove material from a reaction zone.

19. The system of claim 1, comprising a product separation cyclone configured to remove a carbon allotrope from an effluent stream.

20. The system of claim 1, comprising at least two product separation cyclones in a series configuration, wherein each product separation cyclone configured to remove a carbon allotrope from an effluent stream.

21. A method for forming carbon allotropes, comprising:

injecting a reactant gas into a hybrid reactor, wherein the hybrid reactor comprises at least two zones, and wherein each zone performs a function comprising reaction, catalyst separation, attrition, or gas separation, and wherein the reactant gas comprises a carbon oxide and a hydrocarbon;

forming carbon allotropes in the hybrid reactor using a Bosch reaction;

separating catalyst particles from the reactant gas to form a waste gas stream; and

separating the carbon allotropes from the waste gas stream.

22. The method of claim 21, comprising forming the carbon allotropes in a packed bed.

23. The method of claim 21, comprising attriting carbon allotropes from a catalyst particle in a fluidized bed.

24. The method of claim 21, comprising separating a catalyst particle from the reactant gas in an expanded bed area.

25. The method of claim 21, comprising forming the carbon allotropes in a transport reactor.

26. A reaction system for forming carbon allotropes, comprising:

a hybrid reactor configured to form carbon allotropes from gas streams using a Bosch reaction, wherein the hybrid reactor comprises at least two distinct functional zones, wherein each zone is configured to perform a function comprising reaction, attrition, catalyst separation, or gas separation;

a separation system downstream of the hybrid reactor, wherein the separation system is configured to remove carbon allotropes from an effluent from the hybrid reactor;

a feed heater downstream of the separation system, wherein the feed heater comprises a heat exchanger configured to heat a feed gas stream for the hybrid reactor using waste heat from the effluent from the hybrid reactor;

a heat exchanger downstream of the separation system, wherein the heat exchanger is configured to remove water from the effluent;

a gas separation system configured to separate the reactant depleted waste stream into a methane enriched stream and a carbon dioxide enriched stream; and

a mixer configured to blend the methane enriched stream or the carbon dioxide enriched stream into an initial feed stream.

27. The reaction system of claim 26, wherein a reactor zone comprises a fluidized bed, and wherein the fluidized bed attrits carbon allotropes from a catalyst surface.

28. The reaction system of claim 26, wherein a reactor zone comprises a packed bed, wherein the packed bed forms carbon allotropes on a catalyst surface.

29. The reaction system of claim 26, wherein a reactor zone comprises an expanded bed area, wherein the expanded bed area slows a gas stream allowing entrained particles to settle out of the gas stream.

30. The reaction system of claim 26, comprising a separation vessel downstream of the ambient temperature heat exchanger, wherein the separation vessel is configured to separate liquid water from a gas stream.

CLAIMS

1. A reactor system for the production of carbon allotropes, comprising a hybrid reactor configured to form carbon allotropes from a reactant gas mixture in a Bosch reaction, wherein the hybrid reactor comprises at least two distinct zones that perform different functions comprising reaction, attrition, catalyst separation, or gas separation, wherein the hybrid reactor comprises:

a first zone comprising a fluidized bed reactor; and

a second zone comprising a transport reactor, wherein the transport reactor is configured to circulated a portion of the material from the fluidized bed reactor to an opposite end of the fluidized bed reactor.

2. The system of claim 1, wherein the hybrid reactor comprises:

the first zone comprising a fluidized bed disposed in a narrow portion of a reactor vessel comprising the fluidized bed reactor; and

a third zone comprising an expanded area bed disposed in a wider portion of the reactor vessel, wherein a reactant gas stream in the reactor vessel flows from the narrow fluidized bed of the first zone to a wider fluidized bed in the expanded area bed of the third zone.

3. The system of claim 2, wherein the expanded area bed is configured to slow the reactant gas stream to allow catalyst particles to fall back into the narrow fluidized bed.

4. The system of claim 1, wherein the reactor system is configured to divide a reactant gas stream into portions, wherein a first portion of the reactant gas stream is injected into the fluidized bed to maintain fluidization, and a second portion of the reactant gas stream is injected into the transport reactor to push material through the transport reactor.

5. A reactor system for the production of carbon allotropes, comprising a hybrid reactor configured to form carbon allotropes from a reactant gas mixture in a Bosch reaction, wherein the hybrid reactor comprises at least two distinct zones that perform different functions comprising reaction, attrition, catalyst separation, or gas separation, wherein the hybrid reactor comprises:

a first zone comprising a spouted bed;

a second zone comprising a disengaging section configured to allow catalyst particles to drop back to the spouted bed; and

a third zone comprising an expanded bed area, wherein the expanded bed area is configured to slow a reactant gas flow and allow smaller particles to fall back to the spouted bed.

6. A reactor system for the production of carbon allotropes, comprising a hybrid reactor configured to form carbon allotropes from a reactant gas mixture in a Bosch reaction, wherein the hybrid reactor comprises at least two distinct zones that perform different functions comprising reaction, attrition, catalyst separation, or gas separation, wherein the hybrid reactor comprises:

a first zone comprising a packed bed disposed in an outer annulus of the hybrid reactor; and

a second zone comprising a fluidized bed disposed in an inner annulus of the hybrid reactor.

7. The system of claim 6, wherein a reactant gas flows through the packed bed and then into the fluidized bed.

8. The system of claim 6, wherein a material in the packed bed flows out of the bottom of the hybrid reactor into a high velocity stream of reactant gas, and wherein the high velocity stream of reactant gas recirculates the material to the top of the hybrid reactor.

9. The system of claim 7, wherein fresh catalyst is fed into the high velocity stream of reactant gas.

10. A reactor system for the production of carbon allotropes, comprising a hybrid reactor configured to form carbon allotropes from a reactant gas mixture in a Bosch reaction, wherein the hybrid reactor comprises at least two distinct zones that perform different functions comprising reaction, attrition, catalyst separation, or gas separation, wherein the hybrid reactor comprises:

a first reactor comprising:

a first zone comprising a packed bed; and

a second zone comprising a separation zone, wherein the separation zone is configured to remove a gas from the packed bed; and

a second reactor comprising a third zone comprising a fluidized bed, wherein material from the packed bed of the first reactor flows into the fluidized bed of the second reactor.

11. The system of claim 10, wherein the fluidized bed attrits carbon allotropes from the material.

12. The system of claim 1, comprising a catalyst separation cyclone configured to remove catalyst particles from an effluent stream from the hybrid reactor and return the catalyst particles to the hybrid reactor.

13. The system of claim 1, comprising a fresh catalyst feed system configured to provide fresh catalyst to a reaction zone in the hybrid reactor.

14. The system of claim 1, comprising a spent catalyst removal system configured to remove material from a reaction zone.

15. The system of claim 1, comprising a product separation cyclone configured to remove a carbon allotrope from an effluent stream.

16. The system of claim 1, comprising at least two product separation cyclones in a series configuration, wherein each product separation cyclone configured to remove a carbon allotrope from an effluent stream.

17. A method for forming carbon allotropes, comprising:

injecting a reactant gas into a hybrid reactor, wherein the hybrid reactor comprises at least two zones, and wherein each zone performs a function comprising reaction, catalyst separation, attrition, or gas separation, and wherein the reactant gas comprises a carbon oxide and a hydrocarbon;

forming carbon allotropes in the hybrid reactor using a Bosch reaction;

forming the carbon allotropes in a transport reactor;

separating catalyst particles from the reactant gas to form a waste gas stream; and

separating the carbon allotropes from the waste gas stream.

18. The method of claim 17, comprising forming the carbon allotropes in a packed bed.

19. The method of claim 17, comprising attriting carbon allotropes from a catalyst particle in a fluidized bed.

20. The method of claim 17, comprising separating a catalyst particle from the reactant gas in an expanded bed area.

21. A reaction system for forming carbon allotropes, comprising:

a hybrid reactor configured to form carbon allotropes from gas streams using a Bosch reaction, wherein the hybrid reactor comprises at least two distinct functional zones, wherein each zone is configured to perform a function comprising reaction, attrition, catalyst separation, or gas separation;

a separation system downstream of the hybrid reactor, wherein the separation system is configured to remove carbon allotropes from an effluent from the hybrid reactor;

a feed heater downstream of the separation system, wherein the feed heater comprises a heat exchanger configured to heat a feed gas stream for the hybrid reactor using waste heat from the effluent from the hybrid reactor;

a heat exchanger downstream of the separation system, wherein the heat exchanger is configured to remove water from the effluent;

a gas separation system configured to separate the reactant depleted waste stream into a methane enriched stream and a carbon dioxide enriched stream; and

a mixer configured to blend the methane enriched stream or the carbon dioxide enriched stream into an initial feed stream.

22. The reaction system of claim 21, wherein a reactor zone comprises a fluidized bed, and wherein the fluidized bed attrits carbon allotropes from a catalyst surface.

23. The reaction system of claim 21, wherein a reactor zone comprises a packed bed, wherein the packed bed forms carbon allotropes on a catalyst surface.

24. The reaction system of claim 21, wherein a reactor zone comprises an expanded bed area, wherein the expanded bed area slows a gas stream allowing entrained particles to settle out of the gas stream.

25. The reaction system of claim 21, comprising a separation vessel downstream of the ambient temperature heat exchanger, wherein the separation vessel is configured to separate liquid water from a gas stream.