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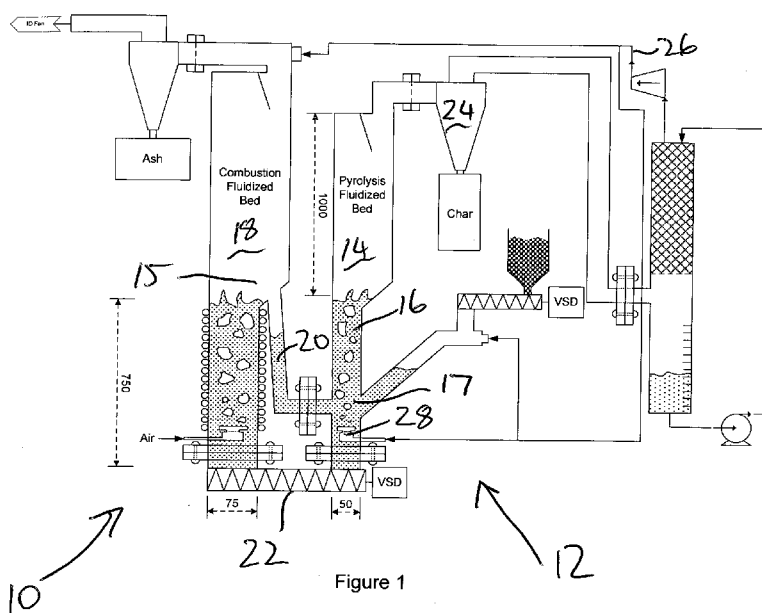
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- (54) Title:** FLUIDISED BED PYROLYSIS APPARATUS AND METHOD



(57) Abstract: The invention provides a carbonaceous feed pyrolysis apparatus including two or more hot particle fluidised beds, and one or more positive displacement apparatus for the transfer of hot particles between two or more of the beds, wherein one or more of the fluidised beds contains a combustion zone. The invention extends to a bio-oil production process, including pyrolysis of a carbonaceous biomass, which process includes 2 or more fluidised beds, a first combustion zone carried out in one or more combustion fluidised beds in which a particulate material is fluidised and heated, and a second pyrolysis zone carried out in one or more pyrolysis fluidised beds in which the hot particles heated in the combustion zone are used for pyrolysis of the bio-mass, said combustion zone being operated at or about atmospheric pressure at a temperature of from 400°C to 1100 °C, typically around 900°C, and the pyrolysis zone being operated at a pressure of from atmospheric to 100 Barg at a temperature of from 400°C to 900°C.



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FLUIDISED BED PYROLYSIS APPARATUS AND METHOD

Field of the Invention

- 5 The invention relates to the pyrolysis of carbonaceous material, such as bio-mass, in a fluidised bed pyrolysis apparatus.

Background to the Invention

- 10 Fast pyrolysis of bio-mass involves rapidly heating solid bio-mass to a temperature of 400°C to 600°C in reducing conditions so that it forms an oil. This is typically done in a fluidized bed, where approximately 60% of the original biomass can be recovered as oil. The pyrolysis is endothermic in nature, and the energy required is typically obtained by heating the fluidized bed indirectly, using electrical heating
15 elements.

The source of heat for heating the fluidised bed is sand which is heated using electrical heating elements to provide the energy for the endothermic reaction. Electrical energy is continuously required in order to maintain the pyrolysis reaction.

20

In order to reduce the electrical energy demand, char produced by the pyrolysis of the bio-mass is recycled as a fuel to the pyrolysis reaction where it is combusted to provide some of the energy required to maintain the pyrolysis temperature, however, this is done at the expense of the char being lost.

25

The inventors have thus identified a need for a more efficient pyrolysis apparatus for the pyrolysis of bio-mass while reducing the need for an external energy source and

possibly allowing for some or all of the char thus produced to be retained for alternative use rather than as a fuel to the pyrolysis.

Summary of the Invention

5

According to a first aspect of the invention, there is provided a carbonaceous feed pyrolysis apparatus including two or more hot particle fluidised beds, and one or more positive displacement apparatus for the transfer of hot particles between two or more of the beds.

10

One or more of the fluidised beds may contain a combustion zone.

One or more of the fluidised beds may contain a pyrolysis zone.

15 The positive displacement apparatus may be a screw feeder or the like.

The screw feeder may be driven by a variable speed drive motor or a constant speed drive motor.

20 The hot particles in the fluidised beds may be sand particles.

The hot particles in the fluidised beds may be primarily catalyst particles.

The catalyst particles may be zeolite particles.

The catalyst particles are typically cracking catalyst particles such as acidic zeolite particles.

- 5 The apparatus may include one or more "L" valves between the combustion and pyrolysis zones so that hot particles may flow from the combustion zone or zones to the pyrolysis zone or zones while impeding the flow of gas in the opposite direction.

10 The apparatus as described above, including a recycle duct for gas produced in the pyrolysis zone to the combustion zone for combustion for the heating of the hot particles.

15 The combustion fluidised bed may include fluidised bed nozzles whereby the fluidising gas, as well as or any combustion gasses, are injected into the fluidised bed through one or more nozzles at a base portion of the fluidised bed.

The pyrolysis fluidised bed may have a similar nozzle arrangement for the fluidising gas.

20 In both cases the nozzle arrangement is selected rather than the standard plenum arrangement permitting removal of the hot particles from the base of the fluidised beds by the positive displacement apparatus with a smaller hold up volume as the hot particles can drop past the nozzles for extraction.

25 Air may enter downwards or upwards through the nozzles into the fluidised beds. Horizontal jets may prevent sand from flowing into an air supply line. The recycle gas

duct or line may enter as close as possible to the nozzle, where it mixes with cold air, and combusts in the fluidised bed.

5 The apparatus may include a char separator after the pyrolysis fluidised bed whereby char can be captured. Typically the captured char may be recycled to the combustion fluidised bed or be used for other purposes unrelated to the operation of the pyrolysis apparatus. The char separator may be a cyclone.

10 According to a second aspect of the invention, there is provided a bio-oil production process, said process including pyrolysis of a carbonaceous bio-mass, which process includes 2 or more fluidised beds, a first combustion zone carried out in one or more combustion fluidised beds in which a particulate material is fluidised and heated, and a second pyrolysis zone carried out in one or more pyrolysis fluidised
15 beds in which the hot particles heated in the combustion zone are used for pyrolysis of the bio-mass, said combustion zone being operated at or about atmospheric pressure at a temperature of from 400°C to 1100 °C, typically around 900°C, and the pyrolysis zone being operated at a pressure of from atmospheric to 100 Barg at a temperature of from 400°C to 900°C, typically 500°C to 600 °C.

20 Pyrolysis gas from the pyrolysis zone may be at least partially recycled to the combustion zone as a source of fuel for the combustion used to heat the particles.

The hot particles may be sand particles, or catalyst particles as described above.

25 The pyrolysis zone may be operated at or about atmospheric pressure.

The use of catalyst in the pyrolysis zone may allow more throughput of bio-mass because more CO₂ is produced and therefore the reaction will be less endothermic.

The catalyst is typically a cracking catalyst such as an acidic zeolite.

5 The area of the combustion fluidized bed may be 2-6 times larger than that of the pyrolysis bed, typically 3 – 4 time larger. This may be more energy-efficient because less of the enthalpy available from the hot particles is used to re-heat the recycled gases, and more enthalpy is used to drive the endothermic pyrolysis reaction.

10 The superficial gas velocity (SGV) may be high in the combustion fluidised bed at a rate of from 1 m/s to 4 m/s, typically 2 m/s, in order to burn as much oxygen as possible in a bed of a given area.

The superficial gas velocity of the recycle pyrolysis gas may be as low as possible while still achieving good fluidisation and thus mixing.

15

The SGV in the pyrolysis fluidised bed may be from 0.2 to 2 m/s, typically 0.5 m/s. It is believed that in this way less enthalpy is lost by means of heating the cold recycle gas. The bio-mass also enters as a solid, and leaves as a gas, thereby increasing the superficial gas velocity as the pyrolysis reaction occurs. The SGV of the recycled pyrolysis gas is controlled or selected in relation to the degree of entrainment of hot particles in the combustion zone and thus if high entrainment occurs at 2.5 m/s, for instance, a low SGV of recycle pyrolysis gas can be selected in order to allow larger throughput of biomass before SGV gets unacceptably high due to vapourization of biomass.

25

Air supply to the fluidized bed may be preheated by exchanging heat from the gases exiting the combustion zone. This may substantially reduce the fluidized bed area required in the combustion zone to heat a given mass flow rate of hot particles. It

also may reduce the amount of carbon that is combusted to form CO₂, making the process more environmentally friendly.

5 The temperature of the combustion fluidized bed may be controlled by varying the rate of transfer of hot particles from the pyrolysis zone to the combustion zone, for example, by varying the speed of a motor driving the positive displacement apparatus such as a screw feeder used for the purpose.

10 The air flow rate is typically fixed to provide a constant SGV through the combustion zone. Fuel flow rate (recycle gas) may be adjusted in order to ensure that there is always sufficient excess oxygen in the gas exiting from the combustion chamber. This may be estimated by measuring CO₂ concentration in the exit gases and inferring excess oxygen.

15 The temperature in the pyrolysis zone is controlled by varying the rate of bio-mass entering the pyrolysis zone. The recycle gas flow rate is typically fixed in order to ensure adequate fluidization in the pyrolysis fluidized bed.

20 The fluidised beds may include disengagement zones. The pressure in the disengagement zones of both the pyrolysis and combustion fluidised beds may be close to atmospheric pressure because of the difficulty of adequate sealing at high temperatures. The pressure in the disengagement zone may be controlled by controlling the speed of an induced draft (ID) fan or by controlling a damper setting in a low pressure line.

25

The pressure in the pyrolysis zone may be controlled by varying the amount of purge gas released from the recycle gas stream.

Where catalyst particles are used instead of hot sand, the combustion zone also serves to regenerate the catalyst as it burns off any coke formed in the pores of the particles during pyrolysis.

5 Description of an Embodiment of the Invention

The invention will now be described, by way of non-limiting example only, with reference to the accompanying flow sheet and diagrammatic drawings, Figures 1 and 2.

10

In Figure 1 is shown a dual fluidised bed pyrolysis apparatus of the invention;

In Figure 2 is shown a nozzle arrangement for the fluidised beds of Figure 1; and

15 In Figure 3 is shown another embodiment of the pyrolysis apparatus of Figure 1.

In the flow sheet 10 of Figure 1, representing an embodiment of this invention, a pyrolysis apparatus 12 and a pyrolysis process is provided for rapidly heating bio-mass to be pyrolysed to bio-oil by mixing it in a pyrolysis fluidised bed 14 with hot particles, in the form of hot sand 16, from a separate fluidised bed operating in combustion conditions.

20

The combustion fluidised bed 18 has a cross sectional area 3 to 4 times that of the cross sectional area of the pyrolysis fluidised bed 14.

25

In Figure 1, the combustion fluidised bed 18 is kept hot, typically around 900°C, by burning combustible gas and char. The hot sand 16 moves from the combustion region 15 to the pyrolysis region 17 by means of an "L" valve 20 which is known in fluidised bed technology.

5

The pyrolysis reaction cools the sand down to 500-600°C, and the cooled sand is returned by a screw conveyor 22 to the hot combustion fluidised bed 18 for re-heating.

10 Some char is entrained with the sand although most of the char will be entrained with the gas and will be collected by the cyclone 24. The char in the sand will burn in the fluidised bed, to provide at least part of the required energy. More energy can be provided from the purge of the pyrolysis gas loop 26. 2/3 of the energy required for combustion can come from the pyrolysis gases which are combustible gases. These
15 gases are introduced directly into the fluidised bed nozzles 28 with the recycle pyrolysis gas being fed concentricly with the air supply pipe into the fluidised bed gas feed pipes to the fluidised bed nozzles. It is preferable to use the gas as the heat source thereby saving the char, because the char is a valuable resource for farmers; it improves the soil when it is worked in.

20

As shown in Figure 2, the air 30 may enter the fluidised beds 14, 18 through the nozzles either downwards, as indicated, or upwards. The horizontal jets are designed to prevent sand from flowing into the air supply line. The gas line 32 enters as close as possible to the nozzle 34 (28), where it mixes with cold air, and
25 combusts in the fluidized bed

In another embodiment represented by the same flowsheet of Figure 1, the sand 16 that is used for the bed of the fluidised beds 14, 18 of the first embodiment is replaced with catalyst that provides a more stable bio-oil than using sand alone. The
30 oxygen content in the oil can be reduced in this way (being removed as CO₂).

Without this treatment, the oils are reactive and oligomerize over time to become an unmanageable sludge. The catalytically treated oil can be blended into refinery feedstocks to form transportation fuel.

- 5 At pyrolytic temperatures, catalysts are prone to coking, which deactivates them. They will last just 5 minutes at these conditions. The catalyst can be renewed by burning off the carbon. The dual fluidised bed system of the invention provides the ideal circumstances for continuous regeneration of the pyrolysis catalyst as the catalyst particles which are returned by the screw feeder to the combustion fluidised
10 bed are heated to around 900°C which regenerates the catalyst continuously.

In Figure 3, the flowsheet of Figure 1 is modified in that the hot sand moves from the combustion region to the pyrolysis region by means of a "Z" valve which is novel in fluidised bed technology.

- 15 Unlike L-valves 20 of Figure 1, in which the bottom pipe section is at 90° from the vertical, the non-mechanical "Z" valve 36 design makes use of an angle closer to 135°, as shown between Bed A 38 (equivalent to 18 in Figure 1) and Bed B 40 (equivalent to 14 in Figure 1) in Figure 3. This allows for the unassisted transport of solids through the valve as only gravity is required as the driving force for the flow of
20 solids.

It is believed to be an advantage of the invention that more efficient pyrolysis is achieved as well as better quality bio-oil, while char which is produced can be used for other purposes.

Claims

1. A carbonaceous feed pyrolysis apparatus including two or more hot particle fluidised beds, and one or more positive displacement apparatus for the transfer of hot particles between two or more of the beds.
2. An apparatus as claimed in claim 1, wherein one or more of the fluidised beds contains a combustion zone.
3. An apparatus as claimed in claim 1 or claim 2, wherein one or more of the fluidised beds contains a pyrolysis zone.
4. An apparatus as claimed in any of the preceding claims, wherein the positive displacement apparatus is a screw feeder driven by a variable speed drive motor or a constant speed drive motor.
5. An apparatus as claimed in any one of the preceding claims, wherein the hot particles in the fluidised beds are sand particles.
6. An apparatus as claimed in any one of claims 1 to 4, wherein the hot particles in the fluidised beds are primarily catalyst particles.
7. An apparatus as claimed in claim 6, wherein the catalyst particles are zeolite particles.

8. An apparatus as claimed in claim 6 or claim 7, wherein the catalyst particles are cracking catalyst particles.

9. An apparatus as claimed in any one of the preceding claims, wherein the apparatus includes one or more valve means between the combustion and pyrolysis zones so that hot particles flow from the combustion zone or zones to the pyrolysis zone or zones while impeding the flow of gas in the opposite direction.

10. An apparatus as claimed in any one of the preceding claims, wherein the apparatus includes a recycle duct for gas produced in the pyrolysis zone to the combustion zone for combustion for the heating of the hot particles.

11. An apparatus as claimed in any one of claims 2 to 10, wherein the combustion fluidised includes fluidised bed nozzles whereby the fluidising gas, as well as or any combustion gasses, are injected into the fluidised bed through one or more nozzles at a base portion of the fluidised bed.

12. An apparatus as claimed in any one of claims 3 to 10, wherein the pyrolysis fluidised bed has a similar nozzle arrangement for the fluidising gas.

13. An apparatus as claimed in claim 11 or claim 12, wherein the nozzle arrangement permits removal of the hot particles from the base of the fluidised beds by the positive displacement apparatus with a smaller hold up volume as the hot particles drop past the nozzles for extraction.

14. An apparatus as claimed in any one of claims 11 to 13, wherein air enters downwards or upwards through the nozzles into the fluidised beds.

15. An apparatus as claimed in any one of claims 3 to 14, wherein the apparatus includes a char separator after the pyrolysis fluidised bed whereby char is captured.

5 16. A bio-oil production process, said process including pyrolysis of a carbonaceous bio-mass, which process includes 2 or more fluidised beds, a first combustion zone carried out in one or more combustion fluidised beds in which a particulate material is fluidised and heated, and a second pyrolysis zone carried out in one or more pyrolysis fluidised beds in which the hot particles heated in the
10 combustion zone are used for pyrolysis of the bio-mass, said combustion zone being operated at or about atmospheric pressure at a temperature of from 400°C to 1100 °C, typically around 900°C, and the pyrolysis zone being operated at a pressure of from atmospheric to 100 Barg at a temperature of from 400°C to 900°C.

15 17. A process as claimed in claim 16, wherein the pyrolysis zone is operated at a temperature of 500°C to 600 °C.

18. A process as claimed in claim 16 or claim 17, wherein pyrolysis gas from the pyrolysis zone is at least partially recycled to the combustion zone as a source of
20 fuel for the combustion used to heat the particles.

19. A process as claimed in any one of claims 16 to 18, wherein the hot particles are sand particles or catalyst particles.

25 20. A process as claimed in any one of claims 16 to 19, wherein the pyrolysis zone is operated at or about atmospheric pressure.

21. A process as claimed in claim 19, wherein the use of catalyst in the pyrolysis zone allows more throughput of bio-mass because more CO₂ is produced and therefore the reaction will be less endothermic.

5 22. A process as claimed in claim 19 or claim 21, wherein the catalyst is a cracking catalyst.

23. A process as claimed in claim 22, wherein the catalyst is an acid zeolite catalyst.

10

24. A process as claimed in any one of claims 16 to 23, wherein the area of the combustion fluidized bed is 2-6 times larger than that of the pyrolysis bed.

15 25. A process as claimed in claim 24, wherein the area of the combustion fluidized bed is 3 - 4 times larger than that of the pyrolysis bed.

26. A process as claimed in any one of claims 16 to 25, wherein the superficial gas velocity (SGV) is high in the combustion fluidised bed at a rate of from 1 m/s to 4 m/s in order to burn as much oxygen as possible in a bed of a given area.

20

27. A process as claimed in any one of claims 16 to 25, wherein the superficial gas velocity (SGV) is high in the combustion fluidised bed at a rate of 2 m/s in order to burn as much oxygen as possible in a bed of a given area.

25 28. A process as claimed in any one of the preceding claims, wherein the SGV in the pyrolysis fluidised bed is from 0.2 to 2 m/s.

29. A process as claimed in any one of the preceding claims, wherein the SGV in the pyrolysis fluidised bed is 0.5 m/s.

30. A process as claimed in any one of claims 18 to 29, wherein the SGV of the recycled pyrolysis gas is controlled or selected in relation to the degree of entrainment of hot particles in the combustion zone.

31. A process as claimed in any one of claims 16 to 30, wherein the air supply to the fluidized bed is preheated by exchanging heat from the gases exiting the combustion zone.

32. A process as claimed in any one of claims 16 to 31, wherein the temperature of the combustion fluidized bed is controlled by varying the rate of transfer of hot particles from the pyrolysis zone to the combustion zone.

33. A process as claimed in claim 32, wherein the varying of the rate of transfer of hot particles is achieved by varying the speed of a motor driving the positive displacement apparatus used for the purpose.

34. A process as claimed in any one of claims 16 to 33, wherein the temperature in the pyrolysis zone is controlled by varying the rate of bio-mass entering the pyrolysis zone.

35. A process as claimed in any one of claims 16 to 34, wherein the recycle gas flow rate is fixed in order to ensure adequate fluidization in the pyrolysis fluidized bed.

36. A process as claimed in any one of claims 16 to 35, wherein the fluidised beds include disengagement zones.

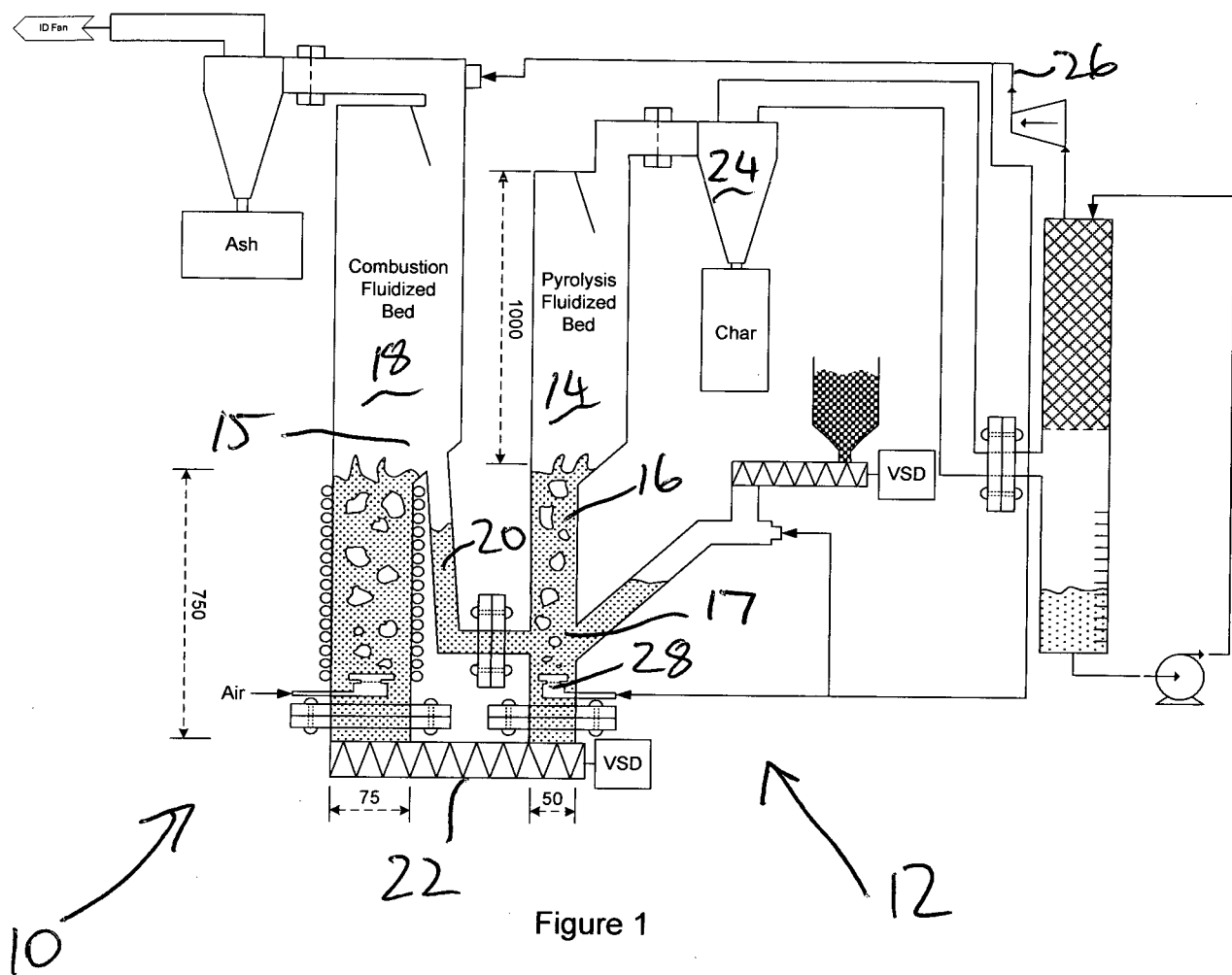
37. A process as claimed in claim 36, wherein the pressure in the disengagement zones of both the pyrolysis and combustion fluidised beds are close to atmospheric pressure because of the difficulty of adequate sealing at high temperatures.

38. A process as claimed in claim 37, wherein the pressure in the disengagement zone is controlled by controlling the speed of an induced draft (ID) fan or by controlling a damper setting in a low pressure line.

39. A process as claimed in any one of claims 16 to 38, wherein the pressure in the pyrolysis zone is controlled by varying the amount of purge gas released from the recycle gas stream.

40. A process as claimed in any one of claims 19 to 39, wherein where catalyst particles are used as the hot particles, the combustion zone also serves to regenerate the catalyst as it burns off any coke formed in the pores of the particles during pyrolysis.

41. An apparatus as claimed in claim 9, wherein the valve is a non-mechanical valve making use of an angle between 120° and 150°, typically 135° between the combustion and pyrolysis zones so that hot particles flow from the combustion zone or zones to the pyrolysis zone or zones while impeding the flow of gas in the opposite direction.



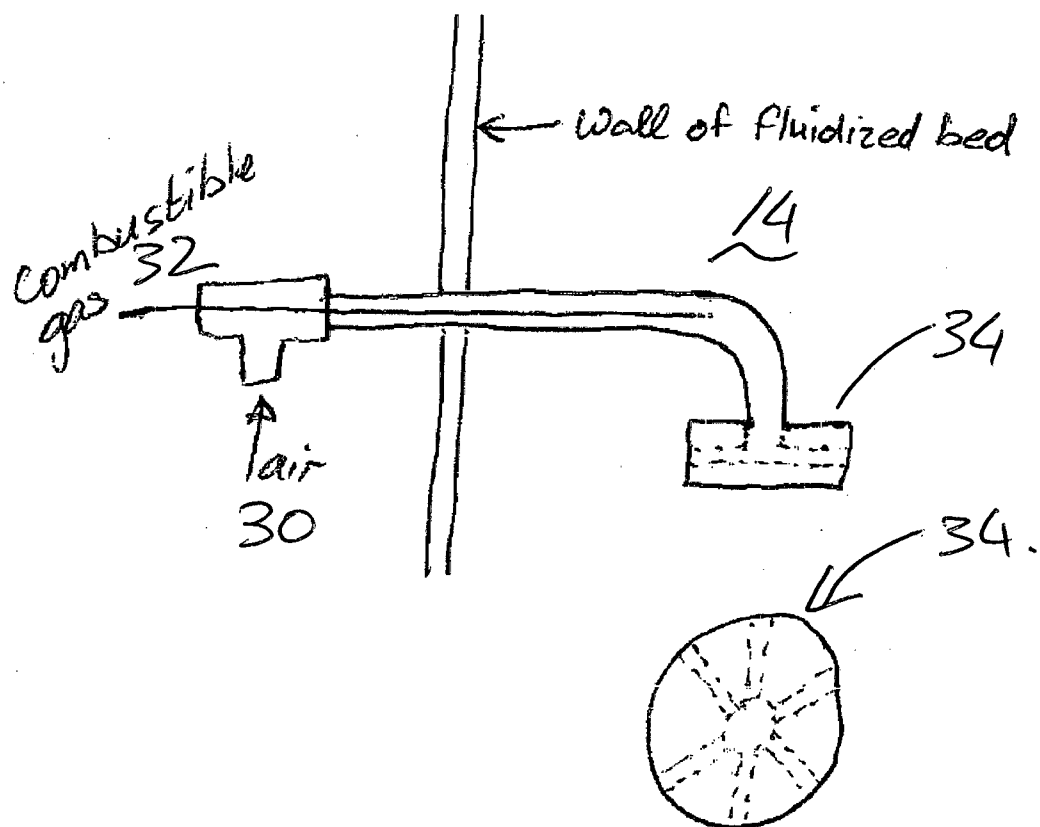


Figure 2

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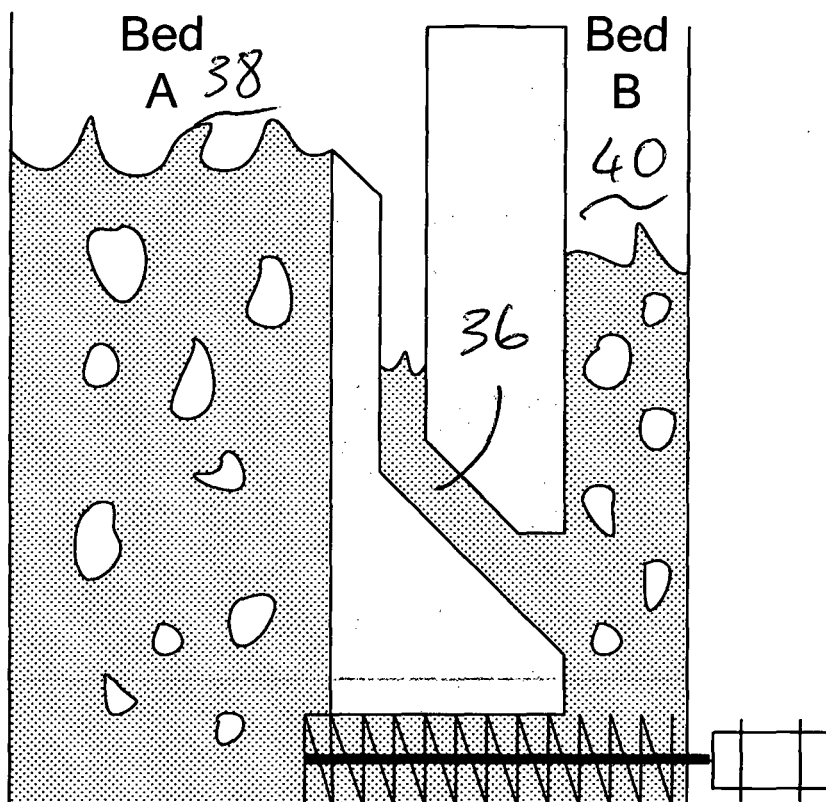


Fig 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/ZA2011/000067

A. CLASSIFICATION OF SUBJECT MATTER
INV. C10B49/22 C10B53/02
ADD. F23C10/00

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)
C10B F23C

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 practical, search terms used)

EPO-Internal, COMPENDEX, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 823 712 A (WORMER ALEX F [US]) 25 April 1989 (1989-04-25) figure 1 column 8, lines 51-59 column 4, line 45 - column 7, line 10 -----	1-15
X	WO 94/24228 A1 (VALTION TEKNILLINEN [FI]; SIPILAE KAI [FI]; SAVIHARJU KARI [FI]; KURKE) 27 October 1994 (1994-10-27) figure 2 claims 1-30 page 20, second paragraph -----	1-41
A	US 4 311 670 A (NIEMINEN JORMA J ET AL) 19 January 1982 (1982-01-19) example 5 figure 6 ----- -/-	1-41



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
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Date of the actual completion of the international search

23 January 2012

Date of mailing of the international search report

31/01/2012

Name and mailing address of the ISA/

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Zuurdeeg, Boudewijn

INTERNATIONAL SEARCH REPORT

International application No
PCT/ZA2011/000067

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 195 17 096 A1 (ENGELHARDT DANIEL [DE]; PFAFF HOLGER [DE]) 14 November 1996 (1996-11-14) claims 1-2 -----	1-41
A	AHO A ET AL: "Catalytic pyrolysis of woody biomass in a fluidized bed reactor: Influence of the zeolite structure", FUEL, IPC SCIENCE AND TECHNOLOGY PRESS, GUILDFORD, GB, vol. 87, no. 12, 1 September 2008 (2008-09-01), pages 2493-2501, XP022679779, ISSN: 0016-2361, DOI: 10.1016/J.FUEL.2008.02.015 [retrieved on 2008-03-14] the whole document -----	1-41

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/ZA2011/000067

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