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(54) Title: PROCESSES AND SYSTEMS FOR PRODUCING HEAT FOR RAPID THERMAL PROCESSING OF CARBONACEOUS MATERIAL

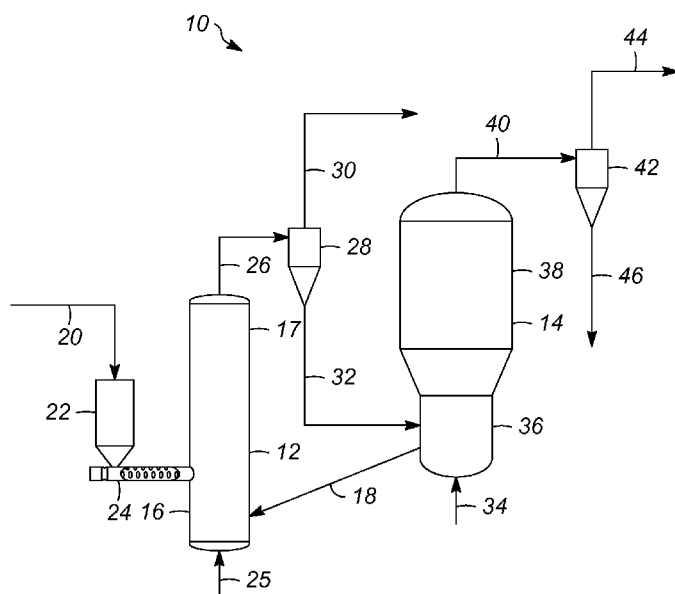


FIG. 1

(57) Abstract: Embodiments of processes and systems for producing heat for rapid thermal processing of carbonaceous material are provided. The process comprises the steps of contacting bubbles of an oxygen containing gas advancing through a fluidized bubbling bed with a grating to form smaller bubbles. The fluidized bubbling bed is contained in a reheater and comprises inorganic heat carrier particles and char. The reheater is operating at combustion conditions effective to burn the char into ash and heat the inorganic heat carrier particles to form heated inorganic particles. The heated inorganic particles are advanced to a reactor.



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PROCESSES AND SYSTEMS FOR PRODUCING HEAT FOR RAPID THERMAL
PROCESSING OF CARBONACEOUS MATERIAL

STATEMENT OF PRIORITY

- 5 **[0001]** This application claims priority to U.S. Application No. 12/960,684 which was filed on December 6, 2010, the contents of which are hereby incorporated by reference in its entirety.

FIELD OF THE INVENTION

- 10 **[0002]** The present invention relates generally to processes and systems for thermal processing of carbonaceous material, and more particularly relates to processes and systems for producing heat for rapid thermal processing of carbonaceous material.

BACKGROUND OF THE INVENTION

- 15 **[0003]** The processing of carbonaceous feedstocks (e.g. biomass) to produce heat, chemicals or fuels can be accomplished by a number of thermochemical processes. Conventional thermochemical processes, such as combustion, gasification, liquefaction, and conventional pyrolysis are typical equilibrium processes and yield relatively low-value equilibrium products including major quantities of non-reactive solids (char, coke, etc.), secondary liquids (heavy tars, aqueous solutions, etc.), and non-condensable gases (carbon dioxide, carbon monoxide, methane, etc.). For example, combustion is used primarily for thermal applications, and gasification typically produces low energy fuel gases with limited uses. Liquefaction and conventional pyrolysis often produce low yields of valuable liquids or gaseous products. In addition, the liquid products that are produced often require considerable secondary upgrading.

- 20 **[0004]** Pyrolysis is characterized by thermal decomposition of materials in the presence of a relatively low amount of oxygen (i.e., significantly less oxygen than required for complete combustion). Typically, pyrolysis has historically referred only to slow conventional pyrolysis whose equilibrium products included roughly equal portions of non-reactive solids (char and ash), secondary liquids, and non-condensable gases.
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- 30

[0005] However, over the past few decades fundamental pyrolysis research has found that high yields of primarily non-equilibrium liquids and gases (including valuable chemicals, chemical intermediates, petrochemicals and fuels) could be obtained from carbonaceous feedstocks through fast (rapid or flash) pyrolysis at the expense of undesirable, slow pyrolysis products. That is, the low-value product distribution of traditional slow pyrolysis can be avoided by using a fast pyrolysis approach.

[0006] Fast pyrolysis is a generic term that encompasses various methods of rapidly imparting a relatively high temperature to feedstocks for a very short time, and then rapidly reducing the temperature of the primary products before chemical equilibrium can occur. Using this approach, the complex structures of carbonaceous feedstocks are broken into reactive chemical fragments, which are initially formed by depolymerization and volatilization reactions. The non-equilibrium products are preserved by rapidly reducing the temperature, and valuable, reactive chemicals, chemical intermediates, light primary organic liquids, specialty chemicals, petrochemicals, and/or high quality fuel gases can be selected and maximized at the expense of the low-value solids (char, coke, etc.), and heavy secondary organic liquids (tars, creosotes, etc.).

[0007] More recently, a rapid thermal process (RTP) system has been developed for carrying out fast pyrolysis of carbonaceous material. The RTP system utilizes an upflow transport reactor and reheater arrangement, and makes use of an inert inorganic solid particulate heat carrier (e.g. typically sand) to carry and transfer heat in the process. The RTP reactor configuration provides an extremely rapid heating rate and excellent particle ablation of the carbonaceous material, which is particularly well-suited for processing of biomass, as a result of direct turbulent contact between the heated inorganic solid particulates and the carbonaceous material as they are mixed together and travel upward through the reactor. In particular, the heated inorganic solid particulates transfer heat to pyrolyze the carbonaceous material forming char and gaseous byproducts including high quality pyrolysis oil, which are removed from the reactor by a cyclone. The cyclone separates the gaseous byproducts and solids of inorganic solid particulates and char, and the solids are passed to the reheater.

[0008] The reheater is a vessel that burns the char into ash and reheats the inorganic solid particulates, which are then returned to the reactor for pyrolyzing more carbonaceous material. An oxygen containing gas, typically air, is supplied to the reheater for burning

the char. The inorganic solid particulates and char are contained in the lower portion of the reheater and are fluidized by the air, forming a fluidized bubbling bed also referred to as the dense phase. The reheater also has a dilute phase that is above the dense phase and comprises primarily flue gas and ash, which are the byproducts formed from combusting the char with the air. Flue gas typically comprises carbon dioxide, oxygen, nitrogen, nitrous oxides (NO_x), sulfur oxides (SO_x), water and other gaseous components. The flue gas and ash are removed from the reheater by a cyclone which separates the ash from the flue gas.

[0009] Many RTP reheaters are relatively large in size in order to adequately support the mass flow rate requirements of the RTP reactors, and have diameters reaching from 20 to 40 feet or greater, and heights reaching from 40 to 70 feet or greater. The dense phase of the fluidized bubbling sand, char and air in these relatively large reheaters may reach depths of from 5 to 20 feet or greater, and the dilute phase may reach heights of from 10 to 30 feet.

[0010] Typically, the air is introduced to the lower portion of the reheater and forms bubbles that rise through the fluidized bubbling bed. As the air bubbles ascend, they also coalesce forming larger and larger bubbles as the air continues to rise. If the fluidized bubbling bed is relatively deep, e.g., 6 to 10 feet or greater, the air bubbles will continue to grow until they burst, throwing the solids of sand and char from the dense phase many feet higher up into the dilute phase. This is problematic for a number of reasons. First, the dilute phase typically provides 10 to 30 feet of space to allow for the solids thrown from the dense phase to fall back down into the fluidized bubbling bed. However, if the air bubbles become large enough by the time they burst, the solids can be thrown many feet higher than the dilute phase and become entrained out of the vessel to the external cyclone for removal of sand with ash from the flue gas. Furthermore, when the bubbles become quite large they can accumulate and take up a significant amount of space in the fluidized bubbling bed. This prevents good mixing of the air, sand and char, which is needed for mass transfer that creates a mixing reaction between the air and the char, and which is also needed for heat transfer from the burning char to the sand. Without good mixing in the fluidized bubbling bed, the air bubbles and the char will not effectively react in the dense phase, resulting in a cooler dense phase. If this occurs, the char that is not burned in the dense phase will continue to burn in the dilute phase. This is called "after burn." After

burn will result in the upper portion of the reheater becoming hotter and since only a small amount of entrained sand is contained in the dilute phase, the heat generated in the dilute phase will not heat the sand. Rather, the heat in the upper portion of the reheater will be exhausted with the flue gas, entrained sand, and ash. The net effect is that the heat generated from burning char will not be effectively recovered by the sand, resulting in cooler sand being passed to the reactor. Moreover, when the bubbles become quite large they take away space from the fluidized bubbling bed, which decreases the residence time for the char to burn in the reheater dense phase, resulting in an incomplete combustion of char to ash and a less efficient process resulting in a poor temperature profile and a temperature that may exceed the design temperature of the equipment in the down stream section with after burn.

[0011] Accordingly, it is desirable to provide processes and systems for producing heat for rapid thermal processing of carbonaceous material by efficiently burning char in a reheater to produce heat that is effectively recovered by inorganic heat carrier particles. Furthermore, other desirable features and characteristics of the present invention will become apparent from the subsequent detailed description of the invention and the appended claims, when taken in conjunction with the accompanying drawings and this background of the invention.

SUMMARY OF THE INVENTION

[0012] Processes and systems for rapid thermal processing are provided herein. In accordance with an exemplary embodiment, a process for providing heat for rapid thermal processing of carbonaceous material is provided. The process comprises the steps of contacting bubbles of an oxygen containing gas advancing through a fluidized bubbling bed with a grating to form smaller bubbles. The fluidized bubbling bed is contained in a reheater and comprises inorganic heat carrier particles and char. The reheater is operating at combustion conditions effective to burn the char into ash and heat the inorganic heat carrier particles to form heated inorganic particles. The heated inorganic particles are advanced to a reactor.

[0013] In accordance with another exemplary embodiment, a system for producing heat for rapid thermal processing of carbonaceous material is provided. The system comprises

a reheater containing a fluidized bubbling bed that comprises inorganic heat carrier particles and char with bubbles of an oxygen containing gas advancing through the fluidized bubbling bed. The reheater comprises a grating disposed in the fluidized bubbling bed. The grating is configured for contacting the bubbles to form smaller
5 bubbles. The reheater is configured to operate at combustion conditions effective to burn the char into ash and heat the inorganic heat carrier particles to form heated inorganic particles. A reactor is in fluid communication with the reheater to receive the heated inorganic particles.

10 BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Embodiments of the present invention will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

15 **[0015]** Figure 1 schematically illustrates a system for rapid thermal processing of carbonaceous material in accordance with an exemplary embodiment;

[0016] Figure 2A is a partial tear away side view of a reheater for producing heat for rapid thermal processing of carbonaceous material in accordance with an exemplary embodiment;

[0017] Figure 2B is a plan view of a grating for the reheater depicted in Figure 2A; and

20 **[0018]** Figure 3 is a partial tear away side view of a reheater for producing heat for rapid thermal processing of carbonaceous material in accordance with an exemplary embodiment.

DETAILED DESCRIPTION

25 **[0019]** The following Detailed Description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding Background of the Invention or the following Detailed Description.

30 **[0020]** Various embodiments contemplated herein relate to processes and systems for producing heat for rapid thermal processing of carbonaceous material. In a reheater, bubbles of an oxygen containing gas advancing through a fluidized bubbling bed are

contacted with a grating that is positioned within the fluidized bubbling bed. The fluidized bubbling bed comprises inorganic heat carrier particles and char. The reheater is operating at combustion conditions effective to burn the char into ash and heat the inorganic heat carrier particles to form heated inorganic particles. The inventor has found that by

5 contacting the gas bubbles with one or more gratings at a predetermined level or levels within the fluidized bubbling bed, the bubbles can be prevented from becoming relatively large. By selectively limiting the size of the bubbles, the inorganic heat carrier particles and char are not thrown a relatively large distance by otherwise larger bursting bubbles, and therefore, remain primarily in the dense phase contained in the reheater without

10 becoming excessively entrained out of the vessel. Further, the gas, inorganic heat carrier particles and char are better mixed as desired for improved mass transfer for providing a mixing reaction between the air and the char, and also as desired for heat transfer between the reactants and the inorganic heat carrier particles, resulting in a hotter dense phase and reduced after burning of the char in the dilute phase. Thus, relatively more heat is

15 recovered by the inorganic heat carrier particles instead of excessive heat in the dilute phase which may exceed the design temperature of the downstream equipment. Moreover, because the size of the bubbles are limited, relatively less space is taken away from the fluidized bubbling bed, and therefore, the residence time for the char to combust with the oxygen containing gas is increased, resulting in a higher conversion of char to ash

20 and a more efficient process.

[0021] Referring to Figure 1, a schematic depiction of an exemplary system 10 for rapid thermal processing of carbonaceous material is provided. The system 10 comprises an upflow transport reactor 12 and a reheater 14. The reactor 12 is a fast pyrolysis system that is designed to achieve a relatively high temperature within a minimum amount of time

25 as well as having a relatively short residence time at the high temperature to affect fast pyrolysis of a carbonaceous feedstock (e.g. biomass including biomass waste). The relatively high temperature is achieved in the lower portion 16 of the reactor 12 using heated inorganic heat carrier particles (e.g., heated sand) that are supplied from the reheater 14. Rapid cooling or quenching of the products is achieved in the Quench Tower

30 down stream of line 30 in order to preserve the yields of the valuable non-equilibrium products. The heated inorganic heat carrier particles that supply the heat required to drive the pyrolysis process are introduced to the lower portion 16 of the reactor 12 via line 18.

[0022] As illustrated, the carbonaceous material is supplied to a feed bin 22 via line 20 where a reactor feed conveyor 24 introduces the carbonaceous material to the lower portion 16 of the reactor 12. Carrier gas, which can be a recirculation gas collected from a suitable location in the system, is also introduced to the lower portion 16 of the reactor 12 via line 25. Preferably, the carrier gas contains less than 1% oxygen, and more preferably, less than 0.5% oxygen so that there is very little oxygen present to minimize or prevent oxidation and/or combustion of the carbonaceous material in the reactor 12.

[0023] Rapid mixing of the heated inorganic heat carrier particles and the carbonaceous material occur in the lower section of the reactor 12. As the mixture advances up the reactor 12 in turbulent flow with the carrier gas, heat is transferred from the inorganic heat carrier particles to the carbonaceous material. In an exemplary embodiment, mixing and rapid heat transfer occurs within 10% of the desired overall reactor resident time. Accordingly, the mixing time is preferably less than 0.1 seconds, and more preferably within 0.015 to 0.030 seconds. Preferably the temperature in the lower portion 16 of the reactor 12 is from 650 to 750°C, and the heating rate of the carbonaceous material is preferably 1000°C per second or greater. The use of the sand or other suitable inorganic particulate as a solid heat carrier enhances the heat transfer because of the higher heat carrying capacity of the inorganic particles, and the ability of the inorganic particles to mechanically ablate the surface of the reacting carbonaceous material.

[0024] As the heated mixture is carried towards the upper portion 17 of the reactor 12 with the carrier gas, fast pyrolysis of the carbonaceous material occurs. In an exemplary embodiment, the temperature in the upper portion 17 of the reactor 12 is from 450 to 550°C. The sand or other inorganic heat carrier particles and the carrier gas, along with the product vapors and char are carried out of the upper portion 17 of the reactor 12 via line 26 to a cyclone 28. The cyclone 28, typically a reverse flow cyclone, removes the solids, e.g., sand and char, from the vapor-phase stream which comprises the carrier gas, non-condensable product gases and the primary condensable vapor products. The vapor phase stream is passed along line 30 for subsequent processing, and the solids are passed to the reheater 14 via line 32.

[0025] As will be discussed in greater detail below, the reheater 14 receives an oxygen containing gas, typically air, via line 34. In an exemplary embodiment, the solids, which are contained in a lower portion 36 of the reheater 14, are fluidized by the gas to form a

fluidized bubbling bed of char, sand and gas. The reheater 14 is operating at combustion conditions to burn the char into ash and flue gas. The energy released from combustion of the char reheats the inorganic heat carrier particles. The heated inorganic heat carrier particles are then returned to the reactor 12 via line 18 for pyrolyzing more carbonaceous material.

[0026] The flue gas, entrained sand, and ash rise to the upper portion 38 of the reheater 14 and are carried out of the reheater 14 via line 40 to a cyclone 42. The cyclone 42, typically a reverse flow cyclone, removes the sand and ash from the flue gas. The flue gas is passed along line 44 for exhausting, subsequent processing, recirculation, or a combination thereof, and the sand and ash is passed along line 46 for disposal or subsequent processing.

[0027] Referring also to Figures 2A-2B, an exemplary reheater 14 for providing heat for rapid thermal processing of carbonaceous material in accordance with the present invention is provided. As discussed above, the oxygen containing gas is introduced to the reheater 14 via line 34, which fluidly communicates the gas to a gas distribution grid 48 disposed in the lower portion 36 of the reheater 14. The gas distribution grid 48 is configured to distribute the gas via a plurality of gas streams 50 into the dense phase 52 of inorganic heat carrier particles and char to produce a fluidized bubbling bed.

[0028] The gas from the gas streams 50 coalesce as it rises through the dense bed 52, forming bubbles 54, which further coalesce to form larger bubbles as they continue to rise. If the depth indicated by double headed arrow Y of the fluidized bubbling bed from the gas distribution grid 48 to the top 56 of the dense phase 52 is substantial, such as, for example, greater than 1.5 or 1.8 meters (5 or 6 feet), the diameter of the bubbles 54 can undesirably become relatively large, e.g., on the order of feet. In order to prevent the bubbles 54 from becoming too large, the inventor has found that a grating 58 or gratings 58 (as illustrated in Figures 2B and 3) can be strategically positioned in the dense phase 52 above the gas distribution grid 48 to limit the size of the bubbles 54. In an exemplary embodiment, the grating 58 is positioned above the gas distribution grid 48 at a distance indicated by double headed arrow X of from 1.2 to 1.9 meters (4 to 6 feet).

[0029] As illustrated in Figure 2B, the grating 58 has a plurality of openings 59 and is circumferentially supported by a support ring 60 or shelf formed in the wall of the lower portion 36 of the reheater 14. However, other suitable means of supporting the grating 58

in the reheater 14 may be used either in combination with or without the support ring 60, such as, for example, one or more I-beams, blocks, and/or welded structures. Preferably the openings 59 have dimensions of from 2.5 to 10 centimeters (cm) (1 to 4 inches). In one example, the openings 59 are rectangular with dimensions of 2.5 x 10, 5 x 10, 7.5 x 10, 10 x 10, 5 x 5, 5 x 7.5, 2.5 x 2.5, 2.5 x 5, 2.5 x 7.5, 7.5 x 7.5 cm (1 x 4, 2 x 4, 3 x 4, 4 x 4, 2 x 2, 2 x 3, 1 x 1, 1 x 2, 1 x 3, 3 x 3 inches), or combinations thereof. Preferably, the grating 58 spans the entire cross-section of the dense phase 52.

[0030] In an exemplary embodiment, the rising bubbles 54 contact the grating 58 to form smaller bubbles. In one example, contacting the bubbles 54 with the grating 58 causes the bubbles 54 to rupture and form smaller bubbles, which continue to rise through the openings 59 of the grating 58 towards the top 56 of the dense phase 52. In another example, contacting the bubbles 54 with the grating 58 includes the bubbles 54 advancing through the openings 59, which subdivides the bubbles 54 into smaller bubbles that continue to rise in the dense phase 52. In one exemplary embodiment, the smaller bubbles have diameters corresponding to the size of the openings 59 preferably resulting in smaller bubbles having diameters of from 2.5 to 10 cm (1 to 4 inches).

[0031] In an exemplary embodiment, the reheater 14 is operating at combustion conditions effective to combust the char with the oxygen containing gas forming ash and flue gas, and to heat the inorganic heat carrier particles to form heated inorganic particles. In one example, the inorganic heat carrier particles are heated to a temperature of from 650 to 750°C. The heated inorganic particles are removed from the reheater 14 via line 18 and advanced to the reactor 12. Some of the ash remains in the dense phase 52 becoming incorporated into the fluidized bubbling bed. However, much of the ash rises into the dilute phase 62 with the flue gas, both of which are removed from the reheater 14 as discussed above.

[0032] Referring to Figure 3, if the depth (Y) of the dense phase 52 above the gas distribution grid 48 is relatively high (e.g. 10 feet or greater), two or more gratings 58 and 64 may be disposed within the dense phase 52 above the grid 48 in order to limit the size of the gas bubbles 54 throughout the fluidized bubbling bed. In one embodiment, a first grating 58 is disposed above the gas distribution grid 48 a distance indicated by double headed arrow X of from 1.2 to 1.9 meters (4 to 6 feet), and the second grating 64 is

disposed above the first grating 58 a distance indicated by double headed arrow Z of from 1.2 to 1.9 meters (4 to 6 feet).

[0033] Accordingly, processes and systems for producing heat for rapid thermal processing of carbonaceous material have been described. The various embodiments

5 comprise contacting bubbles of an oxygen containing gas advancing through a fluidized bubbling bed in a reheater with a grating to form smaller bubbles. The fluidized bubbling bed comprises inorganic heat carrier particles and char. The reheater is operating at combustion conditions effective to burn the char into ash and heat the inorganic heat carrier particles to form heated inorganic particles. By contacting the bubbles with one or
10 more gratings at a predetermined level or levels within the fluidized bubbling bed, the bubbles can be prevented from becoming relatively large. By selectively limiting the size of the bubbles within the fluidized bubbling bed, the inorganic heat carrier particles and char are not thrown a relatively large distance by otherwise larger bursting bubbles, and therefore, remain primarily in the dense phase contained in the reheater without becoming
15 entrained out of the reheater. Further, the gas, inorganic heat carrier particles and char are better mixed as desired for improved mass transfer for creating a mixing reaction between the air and the char, and also as desired for heat transfer between the reactants and the inorganic heat carrier particles, resulting in a hotter dense phase and reduced afterburning in the dilute phase. Thus, relatively more heat is recovered by the inorganic heat carrier
20 particles. Moreover, because the size of the bubbles are limited, relatively less space is taken away from the fluidized bubbling bed, and therefore, the residence time for the char to combust in the reheater is increased, resulting in a higher conversion of char to ash and a more efficient process.

[0034] While at least one exemplary embodiment has been presented in the foregoing

25 Detailed Description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing Detailed Description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment
30 of the invention, it being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended Claims and their legal equivalents.

[0035] In an embodiment the invention is a first process for producing heat for rapid thermal processing of carbonaceous material, the first process comprising the steps of: contacting bubbles of an oxygen containing gas advancing through a fluidized bubbling bed with a grating to form smaller bubbles, the fluidized bubbling bed contained in a reheater and comprising inorganic heat carrier particles and char; operating the reheater at combustion conditions effective to burn the char into ash and heat the inorganic heat carrier particles to form heated inorganic particles; and advancing the heated inorganic particles to a reactor. In an embodiment, the invention is a second process according to the first process wherein the grating has a plurality of openings having dimensions of from 2.5 to 10 cm, and the step of contacting bubbles includes advancing the bubbles through the openings to form the smaller bubbles having diameters of from 2.5 to 10 cm.

[0036] In an embodiment, the invention is a third process according the first or second process wherein the reheater comprises a gas distribution grid proximate a lower portion of the fluidized bubbling bed, and the process further comprising the step of advancing the oxygen containing gas through the gas distribution grid to the lower portion of the fluidized bubbling bed. In an embodiment, the invention is a fourth process according the third process wherein the grating is a first grating that is disposed within the fluidized bubbling bed and is above the gas distribution grid at a distance of from 1.2 to 1.9 meters. In an embodiment, the invention is a fifth process according the fourth process wherein, wherein the reheater comprises a second grating that is disposed within the fluidized bubbling bed above the first grating and the smaller bubbles above the first grating coalesce to form larger bubbles, and the process comprises the step of contacting the larger bubbles with the second grating to form a second plurality of smaller bubbles. In an embodiment, the invention is a sixth process according the fifth process wherein the second grating is disposed above the first grating at a distance of from 1.2 to 1.9 meters.

[0037] In an embodiment, the invention is a seventh process according to any one of the first, second, third, fourth, fifth, or sixth process further comprising the steps of: contacting the carbonaceous material with the heated inorganic particles in the reactor; and operating the reactor at reaction conditions effective to pyrolyze the carbonaceous material. In an embodiment, the invention is an eighth process according the seventh process wherein, wherein the reactor is an upflow transport reactor, and the process further comprises the steps of: introducing the carbonaceous material and the heated inorganic

particles to a lower portion of the upflow transport reactor; and advancing the carbonaceous material and the heated inorganic particles from the lower portion to an upper portion of the upflow transport reactor during pyrolysis of the carbonaceous material. In an embodiment, the invention is a ninth process according the eighth process, wherein the reaction conditions include a temperature of from 650 to 750°C in the lower portion of the upflow transport reactor, and a temperature of from 450 to 550°C in the upper portion of the upflow transport reactor.

[0038] In an embodiment, the invention is a tenth process according to any one of the first, second, third, fourth, fifth, sixth, seventh, eighth, or ninth process wherein the combustion conditions include a reheater temperature of from 650 to 750°C. In an embodiment, the invention is an eleventh process according to any one of the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth, or tenth process wherein the inorganic heat carrier particles comprise sand. In an embodiment, the invention is a twelfth process according to any one of the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth, or eleventh process, wherein the carbonaceous material is biomass.

[0039] In another embodiment the invention is a first system for producing heat for rapid thermal processing of carbonaceous material, the system comprising: a reheater containing a fluidized bubbling bed that comprises inorganic heat carrier particles and char with bubbles of an oxygen containing gas advancing through the fluidized bubbling bed, wherein the reheater comprises a first grating disposed in the fluidized bubbling bed, and wherein the first grating is configured for contacting the bubbles to form smaller bubbles and the reheater is configured to operate at combustion conditions effective to burn the char into ash and heat the inorganic heat carrier particles to form heated inorganic particles; and a reactor in fluid communication with the reheater to receive the heated inorganic particles.

[0040] In an embodiment, the invention is a second system according to the first system further comprising a gas distribution grid proximate a lower portion of the fluidized bubbling bed and configured to fluidly communicate the oxygen containing gas to the fluidized bubbling bed, and wherein the first grating is disposed above the gas distribution grid. In an embodiment, the invention is a third system according to the second system wherein the first grating is disposed above the gas distribution grid at a distance of from 1.2 to 1.9 meters.

[0041] In an embodiment, the invention is a fourth system according to any one of the first, second, or third system further comprising a second grating that is disposed within the fluidized bubbling bed above the first grating, the second grating configured for contacting the bubbles to form smaller bubbles. In an embodiment, the invention is a fifth system according to the fourth system wherein the second grating is disposed above the first grating at a distance of from 1.2 to 1.9 meters. In an embodiment, the invention is a sixth system according to any one of the first, second, third, fourth, or fifth system, wherein the grating has a plurality of openings having dimensions of from 2.5 to 10 cm.

[0042] In an embodiment, the invention is a seventh system according to any one of the first, second, third, fourth, fifth, or sixth system, wherein the reactor is configured to contact the carbonaceous material with the heated inorganic particles and to operate at reaction conditions effective to pyrolyze the carbonaceous material. In an embodiment, the invention is an eighth system according to the seventh system wherein the reactor is an upflow transport reactor having an upper portion and a lower portion, the upflow transport reactor is configured to receive the carbonaceous material and the heated inorganic particles in the lower portion and to advance the carbonaceous material and the heated inorganic particles to the upper portion during pyrolysis of the carbonaceous.

CLAIMS

What is claimed is:

- 5 1. A process for producing heat for rapid thermal processing of carbonaceous material, the process comprising the steps of:
 contacting bubbles of an oxygen containing gas advancing through a fluidized bubbling bed with a grating to form smaller bubbles, the fluidized bubbling bed contained in a reheater and comprising inorganic heat carrier particles and char;
10 operating the reheater at combustion conditions effective to burn the char into ash and heat the inorganic heat carrier particles to form heated inorganic particles; and
 advancing the heated inorganic particles to a reactor.
- 15 2. The process according to claim 1, wherein the grating has a plurality of openings having dimensions of from 2.5 to 10 cm, and the step of contacting bubbles includes advancing the bubbles through the openings to form the smaller bubbles having diameters of from 2.5 to 10 cm.
- 20 3. The process according to claim 1 or 2, wherein the reheater comprises a gas distribution grid proximate a lower portion of the fluidized bubbling bed, and the process further comprising the step of advancing the oxygen containing gas through the gas distribution grid to the lower portion of the fluidized bubbling bed.
- 25 4. The process according to claim 3, wherein the grating is a first grating that is disposed within the fluidized bubbling bed and is above the gas distribution grid, optionally at a distance of from 1.2 to 1.9 meters.
- 30 5. The process according to claim 4, wherein the reheater comprises a second grating that is disposed within the fluidized bubbling bed above the first grating and the smaller bubbles above the first grating coalesce to form larger bubbles, and

the process comprises the step of contacting the larger bubbles with the second grating to form a second plurality of smaller bubbles.

5 6. The process according to any one of claims 1 to 3, further comprising the steps of:

contacting the carbonaceous material with the heated inorganic particles in the reactor; and

operating the reactor at reaction conditions effective to pyrolyze the carbonaceous material.

10 7. The process according to claim 6, wherein the reactor is an upflow transport reactor, and the process further comprises the steps of:

introducing the carbonaceous material and the heated inorganic particles to a lower portion of the upflow transport reactor; and

15 advancing the carbonaceous material and the heated inorganic particles from the lower portion to an upper portion of the upflow transport reactor during pyrolysis of the carbonaceous material.

20 8. A system for producing heat for rapid thermal processing of carbonaceous material, the system comprising:

a reheater containing a fluidized bubbling bed that comprises inorganic heat carrier particles and char with bubbles of an oxygen containing gas advancing through the fluidized bubbling bed, wherein the reheater comprises a first grating disposed in the fluidized bubbling bed, and wherein the first grating is configured
25 for contacting the bubbles to form smaller bubbles and the reheater is configured to operate at combustion conditions effective to burn the char into ash and heat the inorganic heat carrier particles to form heated inorganic particles; and

a reactor in fluid communication with the reheater to receive the heated inorganic particles.

30 9. The system according to claim 8, further comprising a gas distribution grid proximate a lower portion of the fluidized bubbling bed and configured to fluidly

communicate the oxygen containing gas to the fluidized bubbling bed, and wherein the first grating is disposed above the gas distribution grid.

- 5 10. The system according to claim 8 or 9, further comprising a second grating that is disposed within the fluidized bubbling bed above the first grating, the second grating configured for contacting the bubbles to form smaller bubbles.

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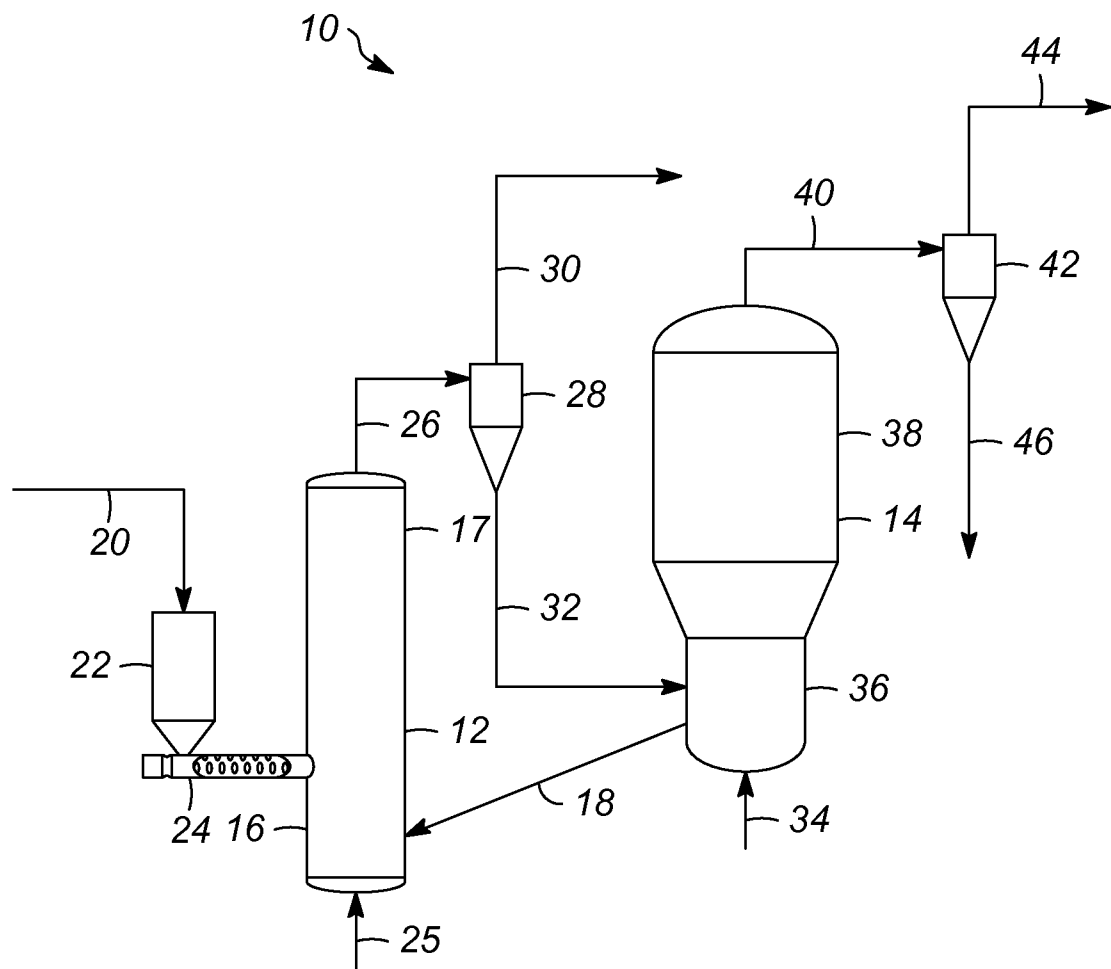


FIG. 1

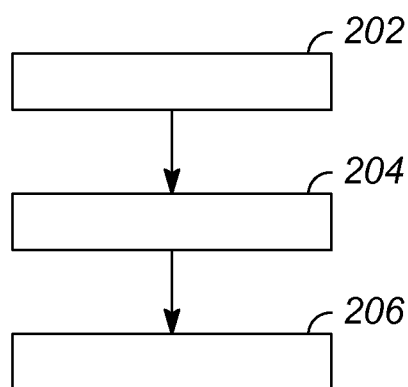


FIG. 2

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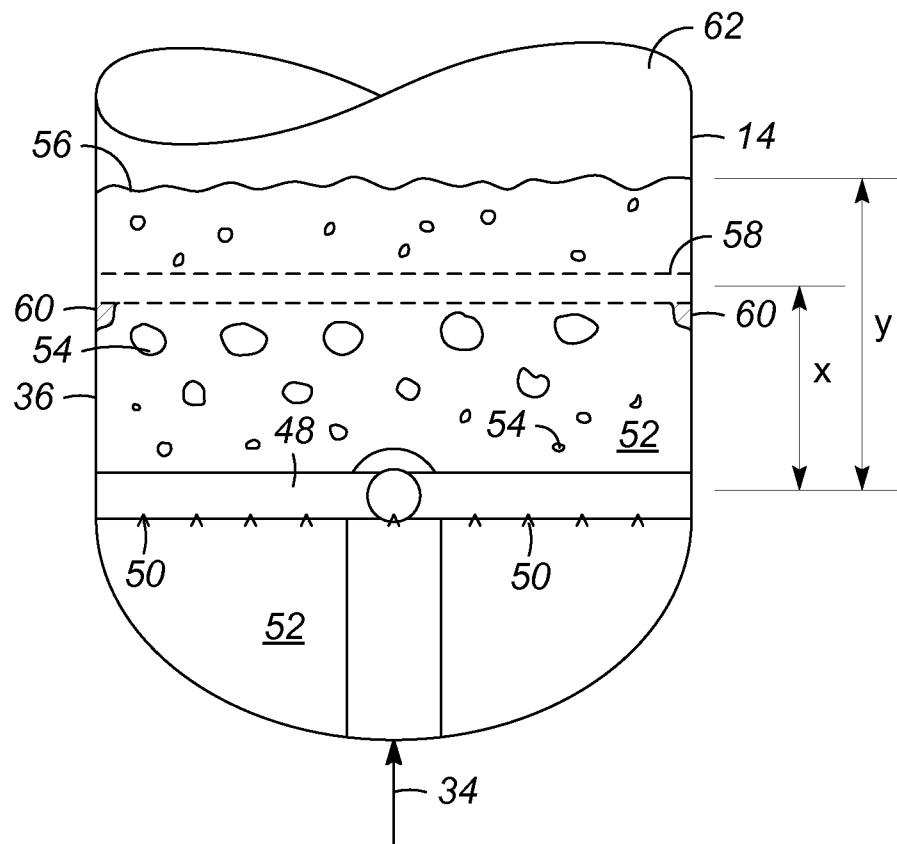


FIG. 3A

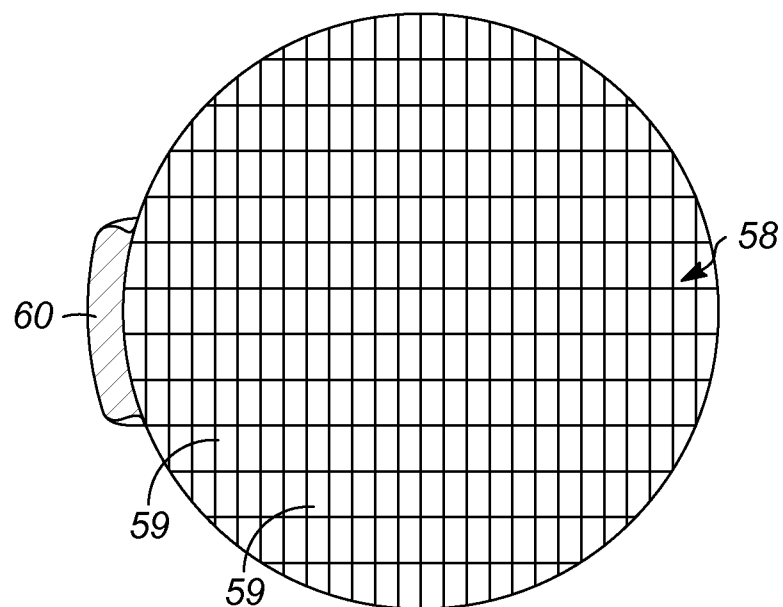


FIG. 3B

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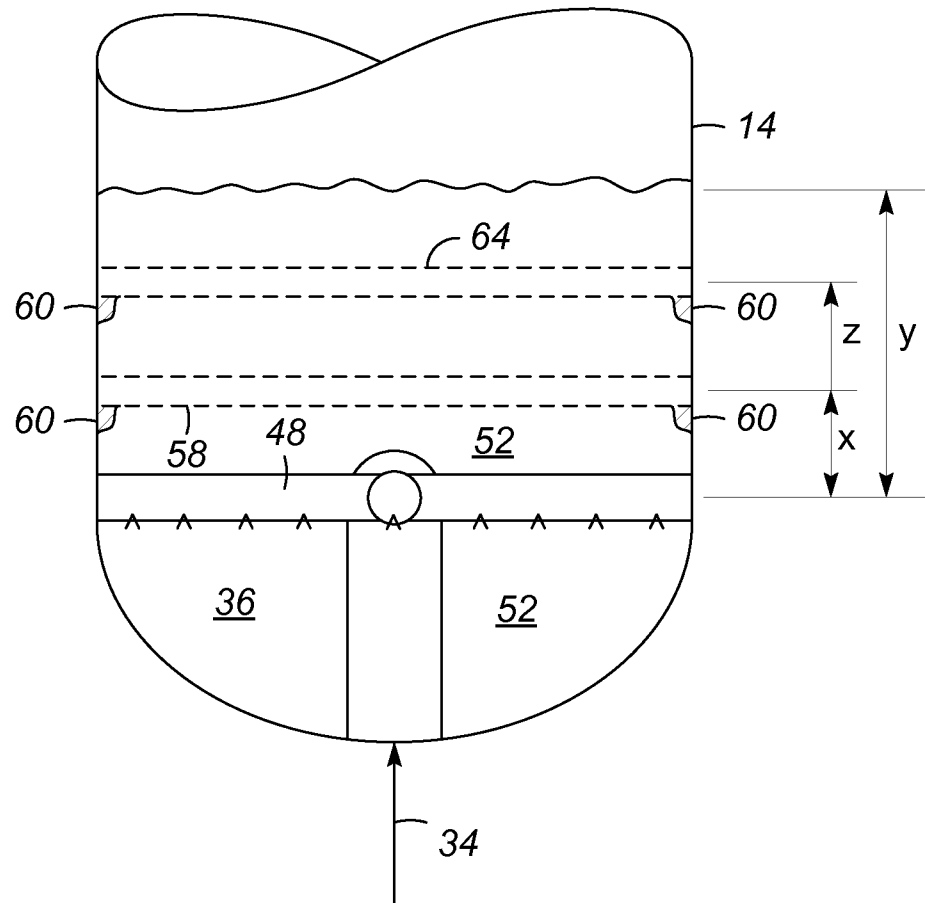


FIG. 4