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(54) **METHOD AND APPARATUS FOR PARTICLE RECYCLING IN MULTIPHASE CHEMICAL REACTORS**

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(57) **ABSTRACT**

Method and apparatus for recycling fine ash particles for a multiphase chemical reactor (MCR), wherein coal is partially oxidized in the MCR to produce an exit gas stream in which fine ash particles are entrained, and wherein the MCR comprises a high temperature region with a temperature at or above a fusion temperature of the fine ash particles, wherein substantially all of the fine ash particles from the exit gas stream are returned to the high temperature region, to achieve improved carbon conversion and reduction in fly ash quantity.

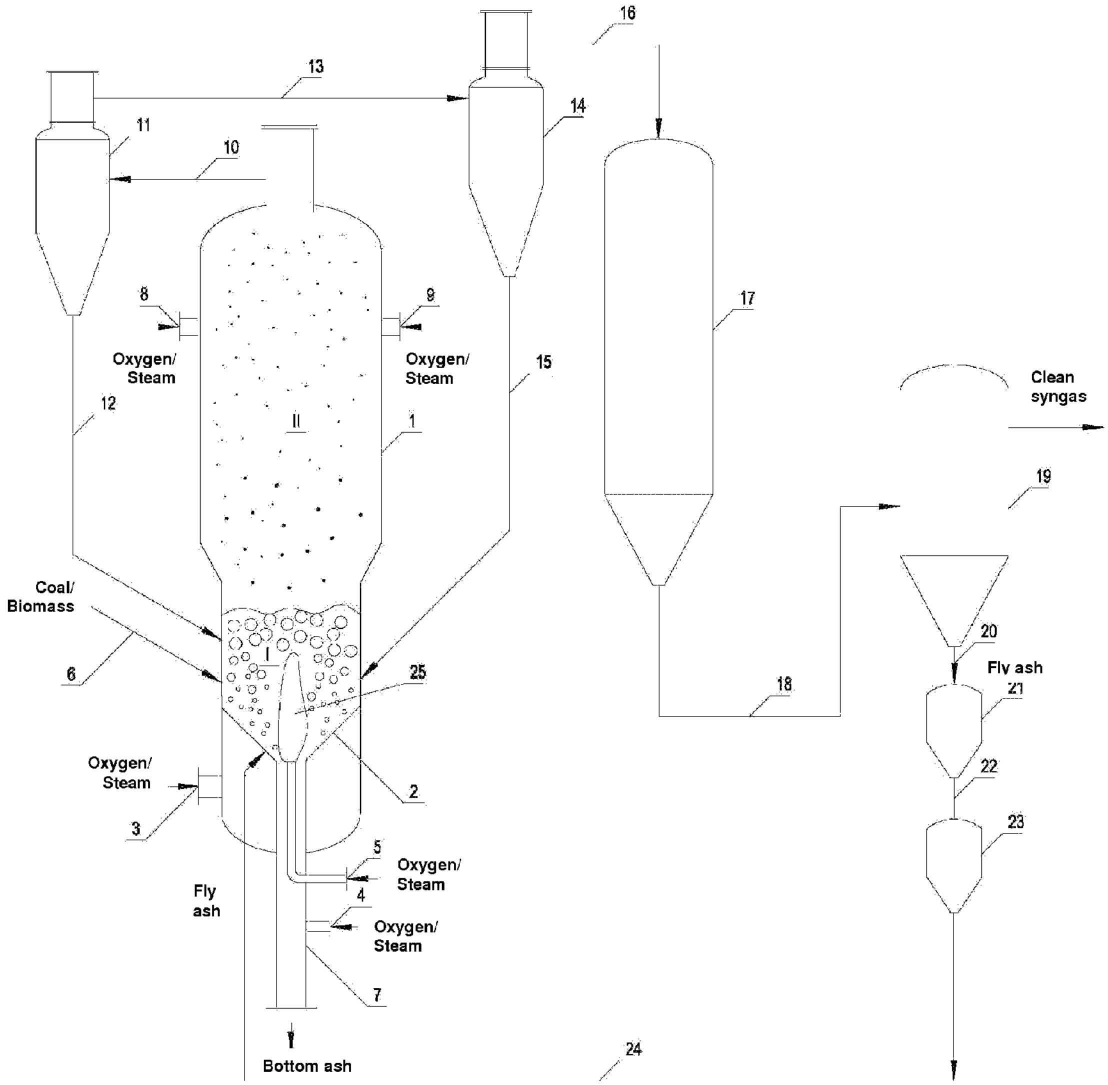
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Figure 1

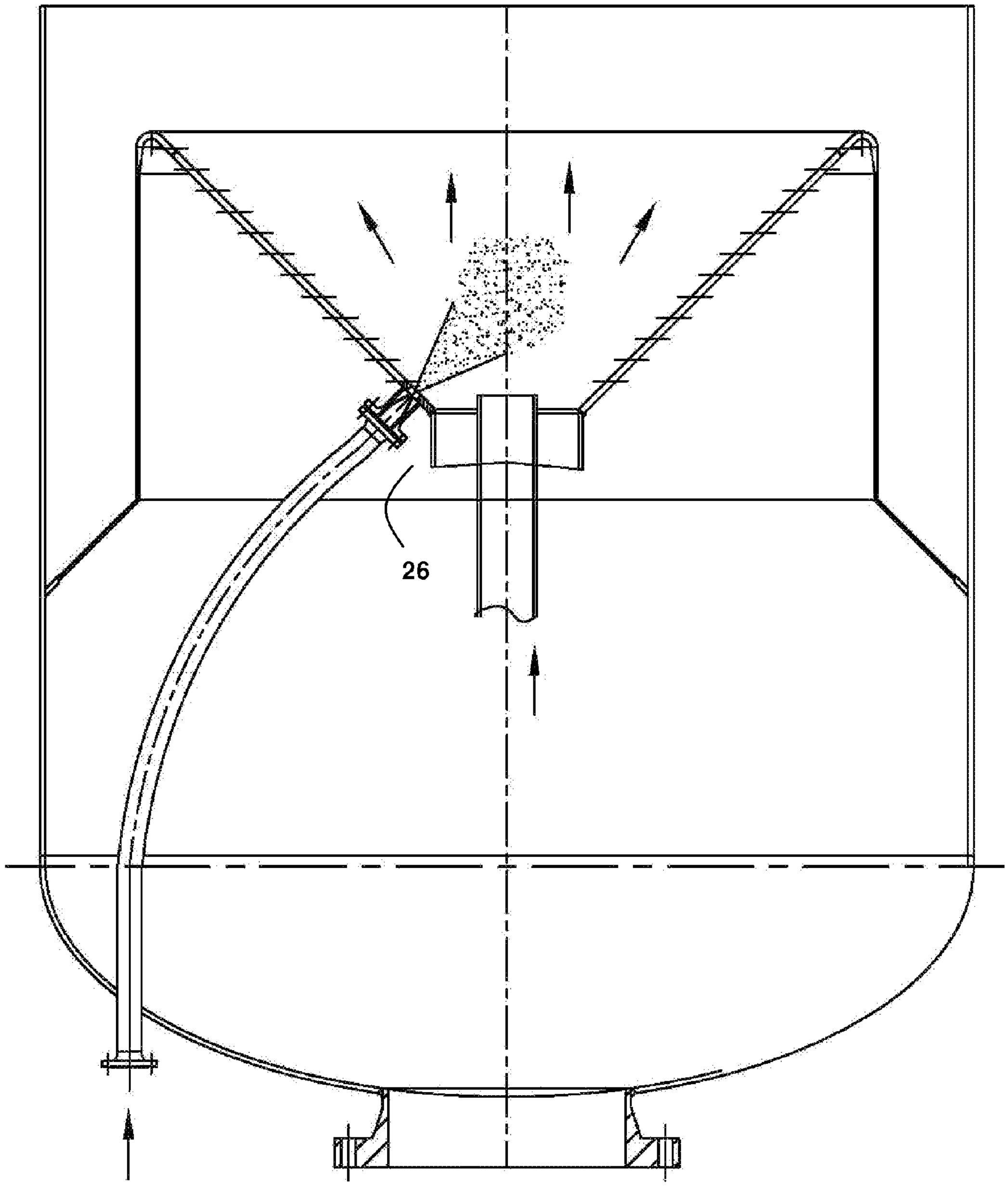


Figure 2

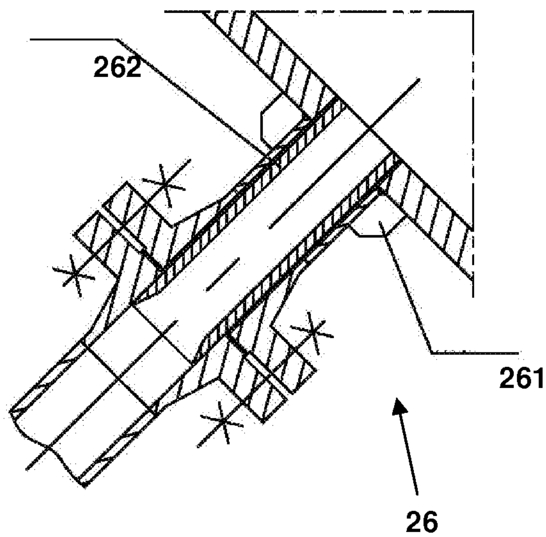
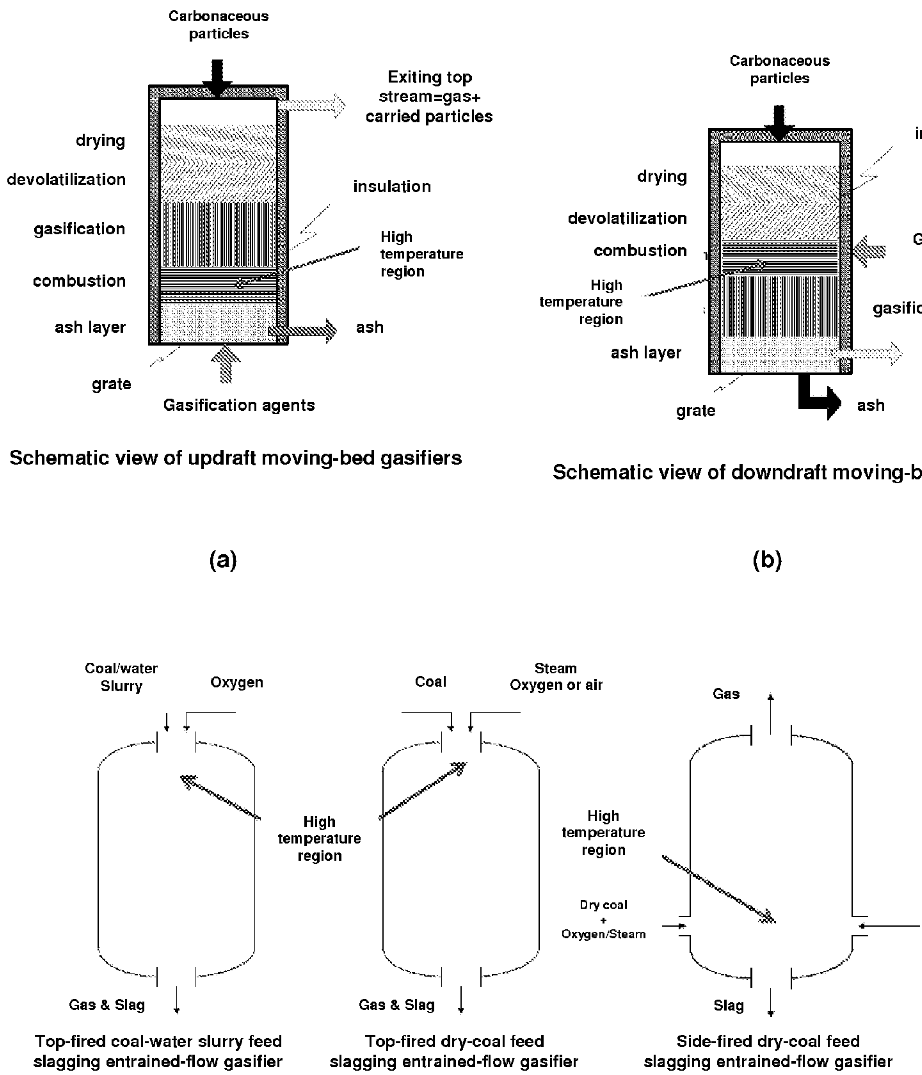


Figure 3



Schematic view of updraft moving-bed gasifiers

(a)

Schematic view of downdraft moving-bed gasifiers

(b)

Top-fired coal-water slurry feed slagging entrained-flow gasifier

(c)

Top-fired dry-coal feed slagging entrained-flow gasifier

(d)

Side-fired dry-coal feed slagging entrained-flow gasifier

(e)

Figure 4

Ash Size Range (mm)	>3.35	2.36-3.35	1.18-2.36	0.83-1.18	0.27-0.83	<0.27
Control （%）	6.39	5.17	10.64	5.1	25.91	46.79
Test（%）	5.54	2.81	5.96	4.31	67.87	13.51

Figure 5

METHOD AND APPARATUS FOR PARTICLE RECYCLING IN MULTIPHASE CHEMICAL REACTORS

FIELD

[0001] The present invention relates to a method and apparatus for collecting and recycling fine solids in a multiphase chemical reactor, e.g. a fluidized bed reactor, an entrained-flow bed reactor, and a fixed bed reactor, in particular as it is used in gasification of coal, biomass and municipal solid waste.

BACKGROUND OF THE INVENTION

[0002] In industrial chemical engineering, several types of reactors are commonly used to carry out a variety of multiphase chemical reactions. Fixed bed reactors (counter-current or co-current), fluidized bed reactors, and entrained-flow bed reactors are typical multiphase reactors. They are often used in gasification of coal, biomass and municipal solid waste (MSW).

[0003] Specifically, a counter-current fixed bed ("up draft") gasifier comprises a fixed bed of carbonaceous fuel (e.g. coal, biomass or MSW) through which the gasification agent (steam, carbon dioxide, oxygen and/or air) flows in counter-current configuration. A co-current fixed bed ("down draft") gasifier is similar to the counter-current type, but the gasification agent gas flows in co-current configuration with the fuel (often downwards, hence the name "down draft gasifier"). The ash is either removed in a dry way or as a slag.

[0004] Pulverized dry fuel is typically fed into an entrained flow gasifier in the presence of oxidants. The fuel and the oxidant are in co-current flow, forming a dense cloud of very fine particles, wherein gasification reactions take place. The high temperature and pressure usually bring about better process conversion as well as higher throughput of a single gasification reactor. However, in some cases, considerable carbon loss can still be found, in the form of ash.

[0005] In a fluidized bed reactor, a fluid with appropriate high velocities suspends granular solids and causes them to behave as a fluid. This process, known as fluidization, possesses many important advantages, which, as a result, is used in many industrial applications, including gasification. In fluidized bed gasification, feedstock particles react with oxygen and steam to produce "syngas", which is a mixture of carbon monoxide, hydrogen and carbon dioxide and other minor gas species. The direct product from the fluidized bed region is referred to as the exit gas stream, containing both the product gas mixture and solids comprising carbon and ash. Generally, the ash is removed dry (fines, or fly ash) or as heavy agglomerates (bottom ash) that defluidize.

[0006] Fly ash carried over is a typical problem for fluidized bed reactors. A fluidized bed gasifier is typically operated at a temperature between 800-1,100° C., which is lower than the typical ash fusion temperature (softening temperature) of 900-1,300° C. of most coal and biomass materials. Due to this relatively low operation temperature, some fuel particles are not fully reacted and converted to gas before they escape the reaction region. And there are considerable amount of not-fully-reacted fuel particles leaving the top of the reactor with the exit gas stream. It's not unusual that the fly ash contains 10% to 60% of un-reacted carbon.

[0007] In order to make the most of the solid phase reactant, and to reduce fines loss at the top, one or more stages of cyclones are often used for such multiphase reactors. These fine particles may be burned in another reactor, but this requires additional equipment and may significantly add operational costs to the process.

[0008] Another typical way to utilize the collected fly ash which contains high carbon contents is to recycle them to the gasification reactor for further reactions. However, there is a possibility that the recycled fly ash would not be readily reacted, especially when the temperature in the reactor is not high enough. In this case, the fly ash would be just cycling within the loop without bringing any apparent improvement in gasification process efficiency.

[0009] Therefore, there is a need for a new method and a new apparatus that can solve the above problems of the prior art.

SUMMARY OF THE INVENTION

[0010] As discussed above, fly ash was routinely returned to the gasifier in an attempt to recycle and reuse the carbon contained therein and reduce ash quantity, but the results have not been satisfactory. The present invention allows the gasification systems to be simplified and capital investment reduced, and the limitation on fines content in feedstock removed or at least relaxed.

[0011] The present inventors recognized, for the first time, that the failure of the prior attempts was due in part to the failure of returning the ash consistently to a high temperature region of the reactor. In fact, prior to the advent of the present invention, no one has attempted to return the fly ash consistently to the high temperature zone of the fluidized bed region. In the case of the fluidized bed reactors, this was in part due to the fact that the fly ash was usually returned to the fluidized bed region using a dipleg connected to the cyclone or baghouse where the fly ash was collected. Due to the high temperature and high particle velocity within the high temperature zone, the dipleg cannot reach the high temperature zone, or it would be quickly and easily eroded.

[0012] The present invention provides a novel and innovative solution to the above problems, and surprisingly and dramatically increased carbon conversion rate and reduced high fly-ash output in coal gasification.

[0013] In one embodiment, the present invention provides a method for recycling fine ash particles for a multiphase chemical reactor (MCR), wherein coal is partially oxidized in the MCR to produce an exit gas stream in which fine ash particles are entrained, and wherein the MCR comprises a high temperature region with a temperature at or above a fusion temperature of the fine ash particles, the method comprising: a) separating the fine ash particles from the exit gas stream, and b) returning the fine ash particles collected in step a) above to the high temperature region.

[0014] The present invention further provides a MCR used in accordance with the method.

[0015] In one embodiment, the MCR of the present invention is a fixed bed reactor, a fluidized bed reactor, or an entrained-flow bed reactor.

[0016] In one embodiment, the MCR of the present invention is used for coal biomass and MSW gasification.

[0017] In one embodiment, the fluidized bed reactor comprises a vertical reaction vessel having a dense phase portion and a dilute phase portion above the dense phase portion, and a distribution grid within the vessel in the dense phase portion defining the bottom of the reaction bed, wherein a high temperature zone is located above the distribution grid, and wherein the fine ash particles are returned to the high temperature zone through the distribution grid.

[0018] In one embodiment, the fine ash particles are returned to the high temperature zone using a pneumatic gas conveyor system. In one embodiment, the gas used for the pneumatic conveyor system does not contain oxygen. In one embodiment, the gas used for the pneumatic conveyor system comprises carbon dioxide, hydrogen, syngas, steam, nitrogen, or a mixture thereof, in a suitable ratio.

[0019] In accordance with another embodiment, one or more cyclones, one or more baghouse filter system, a ceramic filter, or an electric precipitator, or a combination thereof, is used to separate or collect the fine ash particles from the exit gas stream.

[0020] The present invention in one preferred embodiment provides a fluidized bed coal gasification system in which coal-containing fuel particles react with oxygen and steam to produce syngas. The system of the invention, in one embodiment, comprises 1) a fluidized bed reactor vessel which comprises a) an upper portion, wherein a fluidized bed region is formed during operation, and wherein an exit gas stream is formed with fly ash particles entrained therein; b) a lower portion separated from the upper portion by c) a conically shaped distribution plate with its apex pointing downward, having perforations thereon and a central opening at the apex, wherein bottom ash formed in the fluidized bed region can fall through the perforations and collected in the lower portion of the reactor vessel, d) a gas inlet through the opening, through which inlet a gas stream rich in oxygen can be injected into a region just above the distribution plate, wherein during operation a high temperature region is formed due to enhanced combustion of the carbon material in the region; 2) a fly ash collection subsystem wherein fly ash particles are separated from the exit gas stream and collected, and 3) a fly ash recycle subsystem, wherein the fly ash particles collected in the fly ash collection system are returned directly into the high temperature region.

[0021] In one embodiment, in the fluidized bed coal gasification system the fly ash recycle subsystem comprises one or more stages of cyclone; or a bag house, or a ceramic filter; or an electric precipitator or a combination thereof. In another embodiment, in the fluidized bed coal gasification system according of the present invention, the fly ash recycle subsystem comprises a pneumatic gas delivery device for delivering the fly ash.

[0022] In one embodiment, the fluidized bed coal gasification system comprises a pneumatic gas delivery system which has a jet stream outlet through the distribution plate, which jet stream outlet has an opening that delivers the fly ash directly into the high temperature region just above the distribution grid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. **1** is a schematic diagram showing a typical fluidized bed reactor system for coal gasification.

[0024] FIG. **2** shows a specific embodiment of the present invention, wherein the fine particles of the fly ash, collected from the exit gas stream, is delivered though the distribution plate directly into the high temperature region.

[0025] FIG. **3** illustrates in more detail the construction of a pipe connecting with the distribution plate for delivery of fly ash into the high temperature region, in accordance with an embodiment of the present invention.

[0026] FIG. **4** are diagrams showing the general location of the high temperature in (a) updraft fixed gasifier; (b) downdraft fixed bed gasifier; (c) top-fired coal-water slurry feed slagging entrained flow gasifier; (d) top-fired dry-coal feed slagging entrained flow gasifier; and (e) side-fired dry-coal feed slagging entrained-flow gasifier.

[0027] FIG. **5** shows the fly ash size increases when fly ash is returned to the high temperature zone in accordance with a method of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0028] The present invention provides an apparatus, and a related method, useful in a multiphase reactor, such as a fixed bed reactor, an entrained-flow bed reactor, and a fluidized bed reactor, for recycling fine ash particles collected from the exit gas stream. Preferably, the apparatus and method of the present invention are used in a reactor for coal or biomass gasification. When used in coal or biomass gasification, the method and apparatus of the present invention reliably and consistently return the fly ash into a high-temperature reaction region of the reactor, improving coal conversion rate, and reducing fly ash quantity.

[0029] Test results show that in one embodiment, the method of the present invention can convert almost all of the carbon in the reactant coal to syngas, increasing the carbon conversion rate from less than 90% to more than 99%, and almost all ash are collected as bottom ash from the fluidized bed reactor, while all fly ash was able to be returned to the reaction region and fully re-utilized.

[0030] In accordance with an aspect of the present invention, fly ash in the exit gas stream is collected, e.g. via a cyclone, or a bag house, or a combination thereof, and sent back to the high-temperature region inside the gasifier. In the high-temperature region, the fine particles of the fly ash can react rapidly with the steam and oxygen. Due to the small size of the ash particles, and the high temperature (at or above the fusion temperature of the ash particles) and the high speed collision that occurs in the reaction region, the ash particles will fuse to form larger particles, and be discharged to the bottom of the gasifier as bottom ash, greatly diminishing their chance of being blown out as fly ash in the exit gas.

[0031] One of skills in the art will readily recognize that in a multiphase reactors, a region exists where the reaction is most intensive. For example, in the reaction zone of a coal gasifier, wherein oxygen is introduced to coal, the region where oxygen content is higher than other regions would have more rapid or intensive oxidization reaction and as such would have a higher temperature than the rest of the reaction zone. For the purpose of this description, the high temperature region of a coal gasifier has a temperature not lower than the fusion temperature of the fly ash particles, usually not lower than 1,000° C., preferably not lower than 1,100° C. In the case in a fluidized coal gasifier, usually the high temperature region is a region into which from about 10% to substantially all (100%) of the total oxygen consumed by the gasifier is inputted. Preferably the high temperature region is a region into which from about 20%-100%, or from about 30-100%, or from about 40-100%, or from about 50-100%, or from about 60-100% or the total oxygen consumed by the gasifier is inputted.

[0032] FIG. **1** shows a typical fluidized bed reactor system for coal gasification. The central component is a reaction vessel (**1**), frequently cylindrical in shape and made of steel lined in the interior with insulation materials. In the illustrated embodiment, the lower portion of the reaction vessel is narrower than the top portion. The narrower portion is also referred to as the dense phase portion I of the reaction vessel, and the top portion the dilute phase or expansion phase II. A gas distribution grid (**2**) is usually positioned in the vessel in the narrower portion of the vessel, and defines the bottom surface of the fluidized bed. The central portion of the grid may be conical or cylindrical in shape and comprises a passage, usually located in the center of the grid. At the bottom of the passage, a constriction is provided having a fixed opening defining a venturi of fixed throat size to provide a uniform upward gas (oxygen/air and steam) velocity into the vessel and thus into the fluidized bed. In an appropriate position above the distribution plate, coal or other carbon-containing materials are introduced via one or more pipes (**6**) into the vessel, where they partially combust and react with the steam to form syngas. Directing a stream of high velocity gas through the venturi or passage into the reaction vessel causes ash particles in the vessel to agglomerate and eventually discharge through the passage and venturi throat. Additional gas or oxygenating agent may be provided through another inlet (**3**) and is allowed to permeate into the reaction region through the holes in the distribution grid. As discussed above, in the prior art devices, fly ash is formed and exits with the product gas from the top of the vessel.

[0033] The reaction vessel is linked at the top to a first stage cyclone (**11**), which may in turn be linked to an optional second stage cyclone (**14**). Through optional components such as a heat recovering tower (**17**) and a fly ash collector (**19**), which may be a baghouse or other filtering devices, the exit gas stream is separated into clean syngas and fly ash.

[0034] According to an embodiment of the present invention, the fly ash is returned to the reactor region through the distribution grid.

[0035] A cyclone is a device that utilizes the centrifugal force to separate a fluid from particles entrained therein. A conventional cyclone in a fluidized bed reactor is used to separate the gas and solids. A cyclone has at least one tangential inlet for the solids laden gas stream, an outlet for the gas with reduced solids loading and another outlet for the solids collected. For most conventional cyclones, the gas-solids inlet is typically located on the side wall and the gas outlet in the top and the solids outlet at the bottom.

[0036] A high temperature region (**25**) is formed just above the distribution plate, and near the exit of the venturi pipe where the oxygenating agent enters the fluidized bed region. As indicated above, this region is relative rich in oxygen, and relatively more combustion reaction of the coal material maintains the temperature of the entire reaction vessel, and the temperature in this region is higher than the rest of the reaction vessel and above that of the fusion temperature of the fly ash. In prior art devices, much of the fly ash would be blown up, leave this high temperature region, and exit with the syngas before it has had a chance to agglomerate or completely react with the oxygen.

[0037] FIG. **2** shows a specific embodiment of the present invention, wherein the fine particles of the fly ash, collected from the exit gas stream, is delivered though the distribution plate directly into the high temperature region. In one embodiment, the delivery is via a jet stream of carrier gas, e.g. a pneumatic conveyor system, carried in a pipe (**24**), whose exit may protrude above the plate by about 0 to about 1,000 mm.

[0038] The carrier gas may be nitrogen, carbon dioxide, syngas, steam, or a mixture of two or more of the above in any suitable ratio. It is desired that the carrier gas should not contain oxygen to minimize the risk that oxygen will react with the carbon contained in the fly ash which is often at a high temperature. A skilled artisan will recognize that the amount, pressure and speed of the carrier gas for delivering the fly ash to the high temperature region can and should adjusted to ensure that all or substantially all of the fly ash will enter and remain into the high temperature region, so that the remaining carbon is converted into syngas product and the ash particles agglomerate to form large particles and exit the reaction vessel as bottom ash.

[0039] FIG. **3** illustrates in more detail the construction of a connection of a pipe (**24**) connecting with the distribution plate for delivery of fly ash into the high temperature region, in accordance with an embodiment of the present invention. The pipe comprises a head **26** which further includes a ribbed plate (**261**) and a wear resistant lining (**262**).

[0040] FIG. **4** illustrates the high temperature region in fixed-bed as well as in entrained flow gasifiers. In both cases, the high temperature region may be defined as the region inside the reactor where the local temperature is higher than those of other regions, and is generally around the oxygen inject nozzle or grate. In the entrained flow gasifier, the temperature of this region is well above ash fusion temperature

[0041] The invention achieves a high carbon conversion rate and reduces the amount of the fly ash from the gasifier. The invention can be more readily understood by reference to the following examples, which are included merely for purposes of illustration of certain aspects and embodiments of the present invention and are not intended to limit the invention. It will be recognized by one of the skill in the art that many other permutations will accomplish the same objectives of delivering the carbon-containing fly ash directly to the high temperature region of the fluidized bed reactor.

[0042] For example, in one preferred embodiment of the present invention, the system further comprises and a heat recovering tower (**17**), a fly ash collector (**19**), a fly ash lock hopper (**21**) and a fly ash transfer hopper (**23**).

EXAMPLES

Example 1

[0043] A pneumatic gas conveying system was used to delivery the fine fly ash, collected from a baghouse with or without an operational second-stage cyclone, into a high temperature (higher than the hemisphere temperature, or T3, for the fly ash) zone, which is also O_2-rich (>10%), of the gasifier.

[0044] Pneumatic Convey System Design A fully automatic programmable logic control (PLC) system was used, and interlock protections were designed. The connection to gasifier was through a D80 pipe installed with an angle of approximately 45° to the vertical center pipe (**5**) and enters through the distribution plate or grid board.

[0045] Control experiments were performed wherein the fly ash was not returned to the high-temperature zone. Specifically, a coal gasification system, as described in FIG. **1**, was operated for 48 hours, wherein the fly ash were not returned to the gasifier.

[0046] The system was then operated for 72 hours, wherein the fly ash was returned to the high-temperature region via the distribution plate. Other conditions for the operation was kept constant during these two stages. Particularized coal and pure oxygen (99.6%) and steam were used. The pressure inside the reaction vessel was at 321 kPa, with a temperature of about 1020-1024° C. The gas used to deliver the fly ash to the gasifier contains 70% CO_2, with the remainder being H_2 and CO. The coal used has the following characteristics:

TABLE 1

Analysis of Coal Used in the Testing (Wt %)							
	C	H	O	N	S	Ash	Water
Element wt %	55.58	3.62	8.56	0.94	1.10	25.92	4.28

[0047] Once returned to the high-temperature zone, the fine carbon-containing ash articles were nearly completely burned just within about 0.2 seconds, and the ash particles melted or softened, and its density increased. As shown in Table 2 below and in FIG. **5**, the molten or softened ash particles were glutinous and grew in size, most likely after repeated collisions. In contrast, fine coal particles, prior to burning, have a higher fusion temperature and as such were not able to melt or soften or fuse with other coal particles.

TABLE 2

Ash Particle Size Comparison						
	Ash Size Range (mm)					
	>3.35	2.36-3.35	1.18-2.36	0.83-1.18	0.27-0.83	<0.27
Control (%)	6.39	5.17	10.64	5.1	25.91	46.79
Test (%)	5.54	2.81	5.96	4.31	67.87	13.51

[0048] Carbon Conversion Rate; Coal to Net Syngas Rate, and Bottom Ash Analysis

[0049] Using both the ash balance and carbon balance methods of calculation, we determined that the carbon conversion (CC) rate was 99.2%, with an error rate of less than 0.1%. We also calculated the coal to syngas conversion rate, and carbon content in the bottom ash. These results are summarized in Table 3 below.

TABLE 3

Comparison of Carbon Conversion Rate, Cold Gas Efficiency and Bottom Ash Carbon Content			
	Coal Conversion Rate %	Cold Gas Efficiency %	Bottom Ash Coal Content wt %
Control	85.2	70.8	6.6
Test	99.1	81.1	1.5

[0050] Conclusion

[0051] The above test showed that the actual carbon conversion rate reached 99.2%, compared to just a bit above 85% in the control. Almost all ash was discharged as bottom ash with zero fly ash discharge. The test achieved a coal to syngas rate of 1.32 NM^3/kg with a coal LHV 4550 kcal/kg. The represented a 15% reduction of coal consumption or around 20 ton coal savings per day based on a gasifier output of 7500 NM^3/h;

[0052] The test results showed that using the method of the present invention, coal gasification systems can be simplified and capital investment reduced, because at least a second-stage cyclone, and perhaps other fly ash capturing components can be omitted (at least the total bag houses or filters can be reduced) while coal consumption reduced and gas output increased. Furthermore, the limit of coal fine size of 0.15 mm to <15% can also be ignored.

What is claimed is:

1. A method for recycling fine ash particles for a multiphase chemical reactor (MCR), wherein coal is partially combusted in the MCR to produce an exit gas stream in which fine ash particles are entrained, and wherein the MCR comprises a high temperature region with a temperature at or above a fusion temperature of the fine ash particles, the method comprising:

a) separating the fine ash particles from the exit gas stream, and

b) returning the fine ash particles collected in step a) above to the high temperature region.

2. The method according to claim **1**, wherein the MCR is selected from the group consisting of a fixed bed reactor, a fluidized bed reactor, and an entrained-flow bed reactor.

3. The method according to claim **2**, wherein the MCR is a fluidized bed reactor.

4. The method according to claim **3**, wherein the fluidized bed reactor is one used for coal gasification.

5. The method according to claim **4**, wherein the fluidized bed reactor comprises a vertical reaction vessel having a dense phase portion and a dilute phase portion above the dense phase portion, and a distribution grid within the vessel in the dense phase portion defining the bottom of the reaction bed, wherein a high temperature zone is located above the distribution grid, and wherein the fine ash particles are returned to the high temperature zone through the distribution grid.

6. The method according to claim **5**, wherein the fine ash particles are returned to the high temperature zone using a pneumatic gas conveyor system.

7. The method according to claim **6**, where the gas used for the pneumatic conveyor system does not contain oxygen.

8. The method according to claim **6**, where the gas used for the pneumatic conveyor system comprises nitrogen, carbon dioxide, hydrogen, syngas, steam, or a mixture thereof.

9. The method according to claim **1**, wherein one or more cyclones, one or more baghouse filter systems, one or more ceramic filters, one or more electric precipitators, or a combination thereof, are used to separate or collect the fine ash particles from the exit gas stream.

10. A multiphase chemical reactor (MCR) in which coal is partially combusted in the MCR to produce an exit gas stream in which fine ash particles are entrained, and wherein the MCR comprises a high temperature region with a temperature at or above a fusion temperature of the fine ash particles, comprising: a fine ash particle collection system for separating the fine ash particles from the exit gas stream, and a fine ash particle conveyor system for returning the fine ash particles to the high temperature region.

11. The MCR according to claim **10**, selected from the group consisting of a fixed bed reactor, a fluidized bed reactor, and an entrained-flow bed reactor.

12. The MCR according to claim **11**, which is a fluidized bed reactor.

13. The MCR according to claim **12**, wherein the fluidized bed reactor is used for coal gasification.

14. The MCR according to claim **13**, wherein the fluidized bed reactor comprises a vertical reaction vessel having a dense phase portion and a dilute phase portion above the dense phase portion, and a distribution grid within the vessel in the dense phase portion defining the bottom of the reaction bed, wherein a high temperature zone is located above the distribution grid, and wherein the fine ash particles are returned to the high temperature zone through the distribution grid.

15. The MCR according to claim **14**, wherein the fine ash particles are returned to the high temperature zone using a pneumatic gas conveyor system.

16. The MCR according to claim **15**, where the gas used for the pneumatic conveyor system does not contain oxygen.

17. The MCR according to claim **16**, where the gas used for the pneumatic conveyor system comprises nitrogen, carbon dioxide, hydrogen, syngas, steam, or a mixture thereof.

18. The MCR according to claim **10**, wherein one or more cyclones or one or more baghouse filter systems, one or more ceramic filters, one or more electric precipitators, or a combination thereof, are used to separate or collect the fine ash particles from the exit gas stream.

19. A fluidized bed coal gasification system in which coal-containing fuel particles react with oxygen and steam to produce syngas, the system comprising

1) a fluidized bed reactor vessel which comprises

a) an upper portion, wherein a fluidized bed region is formed during operation, and wherein an exit gas stream is formed with fly ash particles entrained therein;

b) a lower portion separated from the upper portion by

c) a conically shaped distribution plate with its apex pointing downward, having perforations thereon and a central opening at the apex, wherein bottom ash formed in the fluidized bed region can fall through the central opening and collected in the lower portion of the reactor vessel,

d) a gas inlet through the opening, through which inlet a gas stream rich in oxygen can be injected into a region just above the distribution plate, wherein during operation a high temperature region is formed due to enhanced combustion of the carbon material in the region,

2) a fly ash collection subsystem wherein fly ash particles are separated from the exit gas stream and collected, and

3) a fly ash recycle subsystem, wherein the fly ash particles collected in the fly ash collection system are returned directly into the high temperature region.

20. The fluidized bed coal gasification system according to claim **19**, wherein the fly ash recycle subsystem comprises one or more stages of cyclone, one or more baghouse filter systems, one or more ceramic filters, one or more electric precipitators, or a combination thereof.

21. The fluidized bed coal gasification system according to claim **20**, wherein the fly ash recycle subsystem comprises a pneumatic gas delivery device for delivering the fly ash.

22. The fluidized bed coal gasification system according to claim **21**, wherein the pneumatic gas delivery system has a jet stream outlet through the distribution plate, and the fly ash is delivered directly into the high temperature region just above the distribution grid.

* * * * *