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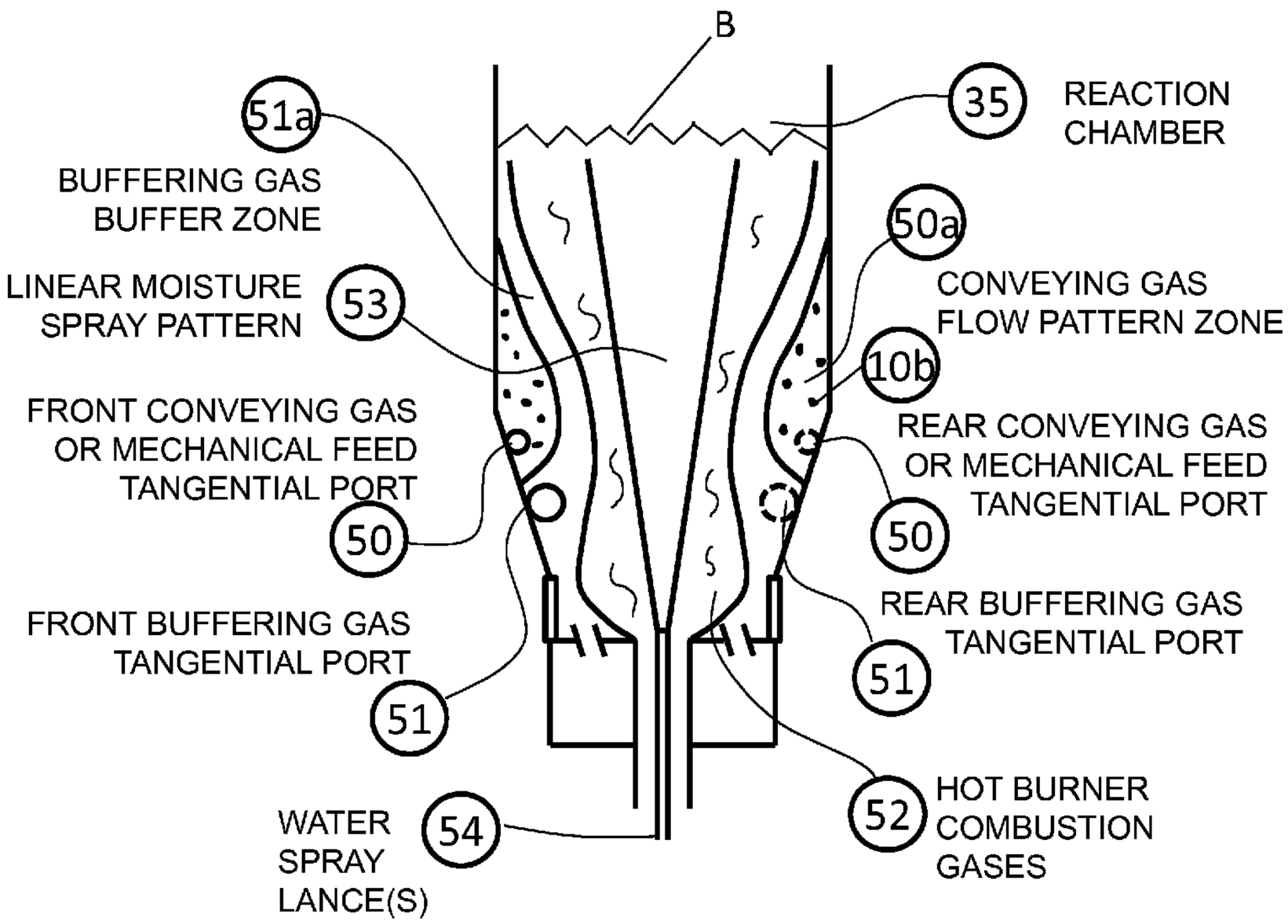

(57) Abrégé/Abstract:
Methods and systems for producing activated carbon from a particulate coal feedstock that include the introduction of a buffering gas, a moisture spray, a finest carbon fraction as a fuel, and certain gas ratios. Different methods and system configurations allow the production of activated carbon or other heat-treated carbons while concurrently avoiding adverse reaction conditions.

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(54) **Title**: OPERATIONAL CONDITIONS AND METHOD FOR PRODUCTION OF HIGH QUALITY ACTIVATED CARBON

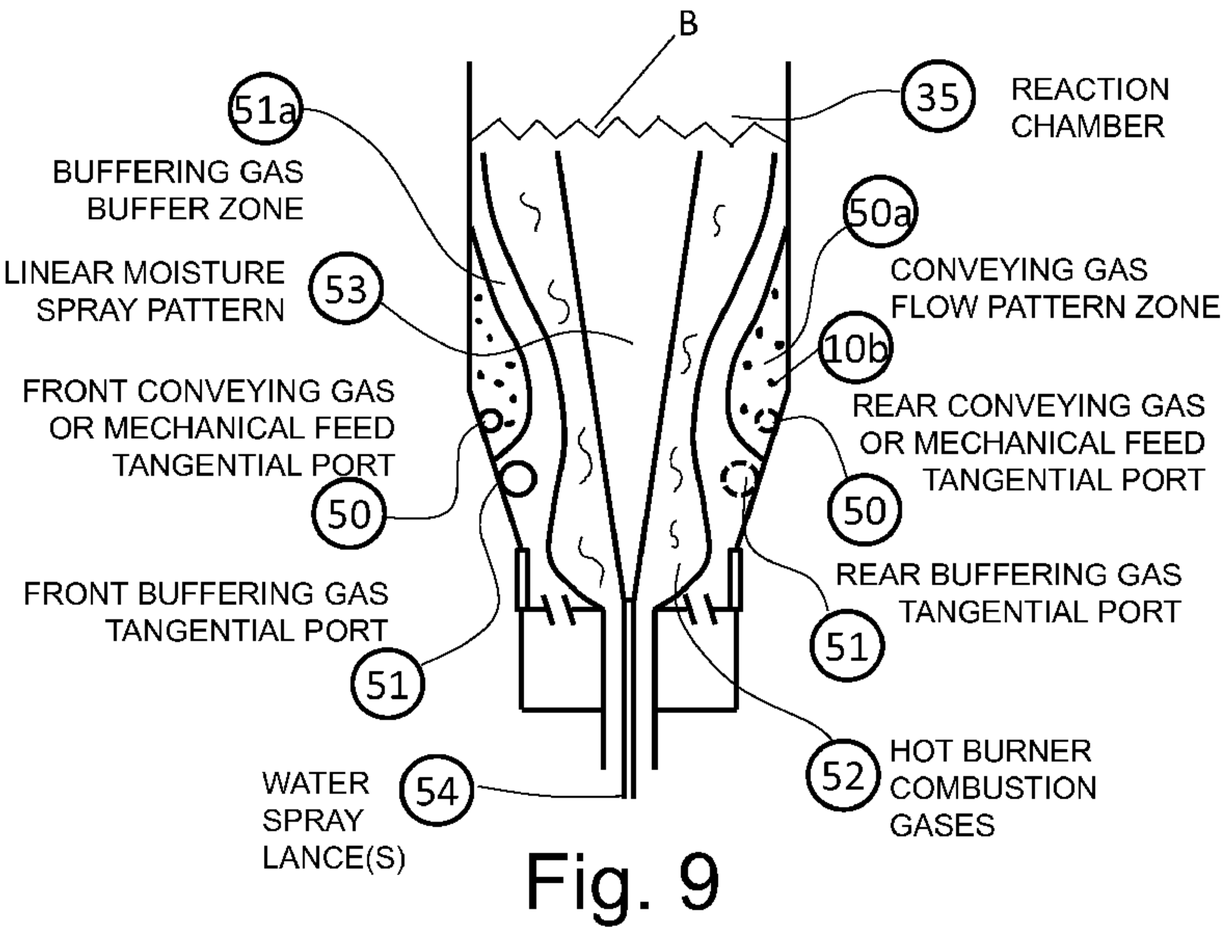

Fig. 9

(57) **Abstract**: Methods and systems for producing activated carbon from a particulate coal feedstock that include the introduction of a buffering gas, a moisture spray, a finest carbon fraction as a fuel, and certain gas ratios. Different methods and system configurations allow the production of activated carbon or other heat-treated carbons while concurrently avoiding adverse reaction conditions.

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Operational Conditions and Method For Production Of High Quality Activated Carbon

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The invention relates to the thermal production of activated carbon and other heat-treated carbons.

Description of the Related Art

[0002] Recent environmental awareness has focused on the need to remove harmful mercury emissions from coal fired power plants. These efforts have led to several developments with regards to effective mercury removal techniques. The most successful method for mercury removal utilizes pulverized activated carbon injected into the flue gas stream of a coal fired power plant. Extensive research in this field has demonstrated that not all activated carbons effectively remove mercury. There are many factors that influence mercury removal effectiveness using activated carbon in coal fired power plants such as coal fuel type, mercury concentrations, etc. One of the largest factors in the ability of activated carbon to adsorb mercury is the activated carbon pore structure. Not all activated carbons have a suitable pore structure and other characteristics required in order to be effective. Often activated carbons are treated with various agents or gases to improve mercury oxidation and removal. Regardless of whether or not the activated carbon is treated with an enhancing agent, invariably the activated carbons used for this application are selected because of specific physical characteristics considered essential for effective for mercury removal. Based on this relatively successful approach to reducing mercury emissions, so-called activated carbon (treated and untreated) is thought to provide very efficient reduction.

[0003] Activated carbon is a term used to describe a carbon material that has been modified to possess a very high surface area that is useful for adsorption, deodorization, and other applications. Thus, activated carbon (AC) refers to carbon that has had its pore structure opened or created. Activated carbon can be produced in two ways. The first is thermal activation where carbon containing material, such as coal, becomes activated by

heating it with steam and/or other activating agents such as CO_2. The second activation process uses various chemicals to create the open pore structure. These treatments remove residual non-carbon elements and produce a porous internal microstructure having an extremely high surface area. A single gram of such material can have 400 to 1200 square meters of surface area, comprising up to 98% of it internal structure.

[0004] Pore structure has several classifications: Micro-pores (<1nm), Mesa-pores (1 to 25nm) and Macro-pores (>25 nm). Mesa-pore AC is well suited for mercury adsorption. AC is also classified by its particulate size range. Generally AC in powdered form of 50 mesh and finer particulate size is referred to as pulverized activated carbon (PAC) and the granular form of 4 to 50 mesh particulates is referred to as granular activated carbon (GAC).

[0005] As previously stated, carbon can be thermally or chemically activated. Chemical activation can be considerably more costly and thermal activation is the current preferred method for producing AC suitable for mercury removal. Thermal AC production methods include rotary hearth furnaces, rotary calciners, and various other forms of calciners and other heat-treatment apparatuses. One of the most common methods of AC product (Fig. 1) can be characterized by two processing stages. The first stage is composed of thermal devolatilization, decomposition, or carbonization of the carbonaceous feed material. The second stage is the gasification or activation of the carbonized char material. Though these stages imply that devolatilization and activation are separate reactions they do in reality overlap to a large degree depending on process conditions. A portion of the carbonaceous feed is invariably activated during devolatilization. Likewise a portion of the carbonaceous feed is further or more completely devolatilized during activation.

[0006] In the devolatilization step, moisture, hydrogen and oxygen are removed from the carbonaceous feed material to open existing pore structure in the carbonaceous feed. During activation, oxidizing gases such as steam, CO_2, or oxygen is used to complete devolatilization and create new additional pore structure through partial or selective gasification of carbon in the devolatilized feed. It is well documented that activation by definition is a selective gasification reaction. The terms activation, gasification and

partial combustion or oxidation are very closely related and in many cases have overlapping meanings. Thermal activation is most often accomplished in direct fire rotary kilns or multi-hearth furnaces, often reaching temperatures greater than 1000 degrees Centigrade.

[0007] While thermal activation is the most widely used method of AC production and has a long and proven track record, operational and capital cost remain high. The cost of existing thermal activation methods is considerable due to the current cost of capital, energy, emissions control and waste disposal. Indeed, devolatilization and activation of material with carbon content typically is thermally treated at temperatures in the general range of 600-1200 °C (1112-2192 °F) over long periods of time and in multiple stages. The time required in each stage can range from minutes to hours.

[0008] Newer concepts for AC production have emerged in which AC is produced in a single reaction vessel through what the inventor terms as "flash activation" processes which refers to any process scheme where devolatilization and subsequent activation reactions require only seconds to complete. These flash activation processes use the principle of rapid devolatilization with heat, moisture, and other oxidizers. Such methods results in varying degrees of concurrent char formation and activation commonly found in partial combustion reactions, coal gasification, and other similar devolatilization schemes.

[0009] Regardless of the scheme used for flash activation, carbonaceous feed, air, heat, and oxidizers such as CO_2, O_2 and moisture, are reacted in a gaseous environment. This reaction produces suitable conditions for devolatilization and activation reactions. Many calciners and other heat-treatment vessels could be operated to produce an activated char product of varying degrees of activation using the flash activation principle. For example the KBR Transport Reaction Vessel Gasifier is a known method of coal gasification. Such a method would produce an activated carbon if the process conditions were altered to favor partial gasification of the carbonaceous feed. Therefore the principle of rapid and concurrent devolatilization and activation (i.e., flash activation) is not in itself unique. It is the quality of the produced AC and the successful commercial adaptation of this principle which are the most important factors.

[0010] Some examples of the adaptation of this principle called by various different names include the "Thief Method for Production of Activated Carbon," the "Sorbent Activation Process (SAP)," and the "PraxAir Hot Oxygen Burner (HOB) PAC Production Method" among others. These methods tie this fundamental devolatilization and activation principle to specific apparatuses such as a boiler, coal power plant flue gas flow, or burner design. However, these methods have not yet demonstrated commercial production capability and do not produce an AC with comparable yield, composition, and overall quality as traditional thermal AC production methods. This is due in part to the general over simplification the complex process variables and reaction vessel design. The prior art does not teach effective reaction vessel design required to produce the optimal reaction vessel thermal, particulate flow, and oxidizing and reducing condition profile necessary to better control process reaction conditions. Furthermore, it often is difficult to control the inadvertent loss of carbon through excessive gasification reactions in heretofore known thermal flash activation processes. The excessive loss of carbon reduces the product yield raising production costs considerably and greatly increases the residual ash content thereby further diminishing the AC product quality. Therefore, the consistent production of the highest quality AC with good product yield (and/or AC of unique or different activation characteristics and applications) remains elusive, particularly on industrial scales of production.

[0011] Thus, there is a need for a rapid and less costly way to produce activated carbon of high quality and/or different activation characteristics and that allows for more precise and versatile controlling of the devolatilization and activation process conditions.

SUMMARY OF THE INVENTION

[0012] It has been discovered that under certain carbon feedstock preparation and/or thermal treatment conditions, improvements in the production and/or characteristics occur. For example, where the starting material, a conveying means, and a gas (e.g., re-circulated combustion flue gases (FGR), air, carbon dioxide, and/or steam) flow to a Reaction Vessel such that the carbon feedstock is introduced into the Reaction Chamber mixed with a tangentially introduced gas creating a threshold gaseous rotational velocity

of at least 60 RPM and preferably about 90 RPM's or greater, most notably, during flash calcination utilizing technology similar to U.S. Patent 7,264,781 B2 , a cyclonic flow is created that results in conditions that are tightly controllable such that charred, devolatilized, and/or more fully activated carbon can be generated from carbonaceous feed sources. This particular method of activation, referred to as flash activation by the inventor, utilizing adapted and new flash calcination technology will hereafter be referred to as flash activation and will subsequently be described in further detail.

[0013] The flash activation of the invention can be practiced in calcination Reaction Vessels. Calcination is by definition a form of thermal treatment in which a material undergoes a chemical change and usually refers to the devolatilization of chemically combined components in the material. Particulate material can be effectively calcined by entraining the material in a gaseous medium and heating the material. This procedure, described as flash activation in the invention, is carried out in different ways depending on the specific calcining characteristics of the material being calcined.

[0014] Almost all calcining methods involve the three operations of preconditioning, calcining and cooling. Preconditioning may include the steps of reducing particle size, screening, drying, and/ or adding liquid or solid additives. One of the main purposes of preconditioning is to produce a uniform, free-flowing substance for the calcining operation. Calcining can be performed utilizing equipment of various designs and, following calcination, the calcined product is separated from the gaseous medium in which calcination took place. The calciner Reaction Vessel (Reactor) and separation cyclone are considered one continuous reaction vessel (Reaction Vessel) since reactions in a pneumatic transport gas flow can proceed until the particulate product is disengaged from the Reaction Vessel gases. While the term Reaction Vessel is used in the description below, it should be understood that the methods of the invention may be practiced in systems having one or more Reaction Vessels alone or Reaction Vessel(s). In addition, the cylindrical heating chamber portion of the Reaction Vessel may sometimes be referred to as the Reaction Chamber. For the purpose of describing the invention the capitalized terms Reactor, Reaction Vessel and Reaction Chamber may be used interchangeably. The calcined product is often further treated, and then cooled and deposited in a storage vessel.

[0015] It has been discovered that providing an activation medium (i.e., water or a water-containing substance) to a particulate coal feedstock such that its moisture content is equal to or greater than the feedstock's naturally occurring (i.e., prior to being mined from the earth) content provides certain benefits during the activation process.

[0016] Thus, in one embodiment, a method for producing activated carbon from a particulate coal includes the steps of loading a particulate coal feedstock with an activation medium such that the water content of the particulate coal feedstock is equal to or greater than that of the coal feedstock's naturally occurring state, conveying the particulate coal feedstock into a heat treatment system, and heat treating the particulate coal feedstock such that at least partial activation occurs.

[0017] In another embodiment, a system for producing activated carbon from a particulate coal feedstock is provided that includes a mixing chamber with an activation medium inlet, a heating chamber having a heat source, a cyclone, and a gas conveying means that conveys the particulate coal feedstock and is in fluid connection with the mixing chamber, heating chamber, and cyclone.

[0018] A few of the key factors required in particular methods of the invention to produce high quality activated carbon with good yields and other unique qualities include:

1. A key factor in the method of the invention is the ability of the flash activation system to accomplish both devolatilization and subsequent activation reactions of carbonaceous feed material in a single Reaction Vessel (Single-Stage Activated Carbon Production) or in two separate Reaction Vessels (Dual-Stage Activated Carbon Production).
2. The carbonaceous feed sources can include various particulate hydrocarbons such as various forms of coal, such as lignite coal, which may be ideally suited. Other particulate feedstock materials include cellulous-based materials including wood fibers, coconut shells, etc. Many other carbohydrate feed materials may also be possible.

3. Another key factor relating to the carbonaceous feed is the control of particulate feed size distribution. The control of the particulate feed size distribution is important because the rate of devolatilization and activation varies widely depending of particle size. Therefore granular feed material and pulverized feed material will experience different rates of heating, devolatilization and activation when heated at the same time and under the same conditions. In most cases the finer feed will experience excessive activation or gasification resulting in product loss while the more granular feed will experience a lesser degree of activation leading to a reduction in product quality. Carbonaceous feed particulate size should be within a predetermined standard size deviation from the mean particle size for a particular carbonaceous feed type. The inventor has determined that the following carbon feedstock ranges in uniformity of size are particularly preferred:

- at least 90% of the feedstock is within one-half an order of magnitude in size for particles coarser than 0.40mm
- at least 90% of the feedstock is within one-quarter an order of magnitude in size for particles 0.40 mm or smaller in size
- If feedstock overlaps these size ranges, having at least 90% of the particles within one-half to one-quarter an order of magnitude in size.

4. Another method for controlling carbonaceous feed size distribution as well as further increasing the quality of the activated carbon produced and improving operational efficiencies involves separating the finest fraction of carbonaceous feedstock material prior to calcination. The finest fraction can be defined as the finest 15 percent or less of the carbonaceous feedstock material. Preferably, this finest fraction includes feed material finer than 170 mesh. The finest fraction of the carbonaceous feedstock material competes with the coarser fractions for activating gases. The finest fraction has the highest surface area and therefore more readily reacts with the activating gases to the point where such particles excessively activate or gasify. This improves product quality by lowering the amount of fines in the carbonaceous feedstock material thereby tightening the feed size distribution and facilitating more uniform calcination. Once removed this finer fraction of carbonaceous feedstock material can be pulverized and

utilized as a solid fuel for the burner. The combustion in the burner of the finest fraction of the carbonaceous feedstock material is beneficial in lowering the operating cost of calcination by providing a significant portion of the heat required for calcination. Combustion through the burner provides complete or nearly complete combustion of the finest fraction of carbonaceous material. The resultant ash byproduct of this combustion is exceedingly fine and will represent a higher fraction of the cyclone carryover particulates, thus helping to separate a significant portion of the ash generated from the solid fuel burner from the activated carbon product.

5. Various techniques can be utilized to introduce carbonaceous feed into the flash activation Reaction Vessel. These techniques include operating the burner in such a manner that the fuel, such as coal, is partially combusted under oxidizing to reducing conditions thereby resulting in devolatilized char formation and injecting the carbonaceous feed material directly into the hot tightly swirling burner gases downstream of the process burner. A typical method is the pneumatic injection the carbonaceous feed material with a conveying gas tangentially around the hot burner gases down stream of the process burner creating or sustaining a cyclonic flow through a significant portion of the Reaction Vessel. In addition the process burner can also be designed to impart rotational momentum to assist in the creation of cyclonic flow within the Reactor. However, carbonaceous feed material can also be pneumatically conveyed to the Reaction Chamber and mixed immediately upon entering the Reaction Chamber with a buffering flow of air, FGR, other gases or a combination, that were previously or concurrently introduced into the Reaction Chamber thereby creating the desired cyclonic feed material flow pattern. Alternatively, carbonaceous feed material can be mechanically conveyed to the Reaction Chamber and mixed immediately upon entering the Reaction Chamber with a buffering gas flow of air, FGR, or other gas(es).

6. Another key benefit of the invention is the ability to introduce a buffering air/gas source prior to the material feed injection, whether mechanically or pneumatically injected. The buffering gases would be introduced separate of the

conveying air/gas or mechanical feed injection such that the streams do not immediately mix. This feature allows for the additional buffering of adverse reaction conditions during the first milliseconds to seconds of calcination. The previous section discussed the addition of a buffering gas concurrently with a conveying gas stream (i.e., pneumatic injection) or relatively concurrently with mechanical material feed injection. While that method remains generally effective, a percentage of the mixed carbonaceous feed material and gaseous flows can travel in close proximity to the hot burner flame increasing the potential for carbonaceous feed to interact directly with the excessively hot initial burner gases. Therefore an improved method of calcination involves allowing a buffering gas to surround the burner flame distinctly prior to mixing or being mixed with the carbonaceous feed material. To accomplish this additional buffering effect a buffering gas is added around the circumference of the flame by either by injecting gases tangentially around the flame distinctly prior to the injection of particulate feed material or by introducing the buffering gases linearly into the Reactor uniformity around the hot flame thereby creating a buffer zone substantially free of feed material between the hot flame and the subsequently injected feed material. By introducing the buffering gas earlier in the Reactor the buffering gas flow is able to more fully develop between the initial hot flame and the Reactor wall prior to carbonaceous feed material injection. The buffering gases can be comprised of recirculated flue gases, air, moisture, or gases such as CO_2 and nitrogen. The volume and composition of these gases can be adjusted to not only improve buffering of the feed material from excessive temperatures but to provide and/or improve downstream calcination reactions. Buffering gases that are injected tangentially prior to the injection of carbonaceous feed material can also provide a significant portion of the motive force required to ensure proper cyclonic rotational velocities within the Reactor.

7. Another key factor is the need to prevent carbonaceous feed particulates from undergoing adverse reaction conditions such as overheating and/or favoring partial combustion reactions thereby affecting the yield and pore structure. The process must also be able to retain the coarser feed material longer than the finer

material. This can all be accomplished by the cyclonic flow pattern within the Reactor created by the injection of carbonaceous feed either mechanically or pneumatically and using a conveying gas and/or the injection of buffering gas streams such as re-circulated flue gases or steam to create a cyclonic material flow pattern. Cyclonic gas flow rotational velocities within the Reactor should be a minimum of about 60 RPM but more preferably at least about 90 RPM average velocity and even more ideally in the 120 to 240 RPM range. Cyclonic flow in the Reactor in conjunction with the feed conveying gas and or buffering gas composition creates a more uniform AC product by buffering the carbonaceous feed from excessive Reaction Vessel temperatures caused by the burner flame and/or from excessive partial combustion of the feed. By utilizing this method, adverse carbon particle surface reactions, ash fusion, excessive gasification and product loss is significantly avoided. In addition cyclonic flow in the Reactor increases particulate retention time by creating a helical material flow pattern thereby increasing the particle path length.

8. Pneumatic conveying carbon feedstock into a flash activation Reaction Vessel utilizing a mixture of a conveying gas and a buffering gas. This results in the ability to control the Reaction Chamber flow profile in which devolatilization and activation predominately occurs in distinct regions of the Reaction Chamber. By controlling the rate of addition, moisture percentage, and/or activation content of a buffering gas independently of the conveying gas, the reaction time, temperature, oxidizing and reducing conditions, and other aspects of the devolatilization and activation process stages can be controlled using a single or multiple vessels. The conveying gases and buffering gases can and typically would differ in composition. Alternatively carbonaceous feedstock can be introduced into the Reaction Chamber using mechanical conveying and immediately thereafter mixed with an air/gas source with the desired composition and volume within the Reaction Chamber. The air/gas source can be concurrently introduce with the feed material or injected previous to the material feed. This would enable the creation of substantially similar material flow conditions within the Reaction Chamber achievable with pneumatic conveying.

9. Another key factor is the Reaction Chamber size. Different carbonaceous materials require differing retention times for proper devolatilization and activation. Since the Reaction Chamber is a fixed geometry retention time requirements can only be primarily controlled by particle size, gas flow rates and cyclonic rotational velocities. Proper sizing of the Reaction Chamber for a given type of carbonaceous feed and desired level of activation is required. Calculated retention time requirements, minimum conveying gas velocities, and favorable cyclonic rotational velocities are used to determine the Reaction Chamber sizing constraints. The inventor has determined that the Reactor Reaction Chamber inside geometry is preferably 6 to 1 (length to diameter) or greater with about 4 to 1 being considered the minimum.

10. Another key factor is the ratio of heat provided by the burner and the rate of heat provided by the carbonaceous feed stock. The heat provided by the burner includes all heat sources passing through the burner such as various fuel sources, air temperature, flue gas re-circulation, etc. The percentage of heat from the burner can range from 20% to 60% of the total heat required with the remaining heat provided by the partial combustion of the carbonaceous feed stock. Also, the heat generated through the burner should be between 4,000 to 10,000 BTU per pound of activated carbon.

11. Another key factor for rapidly controlling calcination conditions is the injection of moisture through the center portion of the burner flame down the linear length of the Reactor through one or more spray lances. The moisture and carbon are introduced into the Reactor such that the carbon feedstock is not contacted by the moisture until the feedstock undergoes at least one revolution or travels at least one half reactor diameter within the Reactor, and wherein moisture is injected into and present in the Reactor before the carbon feedstock enters. Thus, the moisture injection occurs prior to the injection of the carbonaceous feed material into the Reactor vessel and only contacts or mixes with the carbonaceous feed material after the carbonaceous feed material cyclonic flow pattern and linear flow has been established. The cyclonic flow pattern is generally considered established one half of the Reactor diameter downstream from the carbonaceous

feed injection. This linear injection of moisture is useful in further tempering peak flame temperatures and providing moisture evenly for downstream calcination processes such as activated carbon. The moisture injection can also be utilized to modify the reaction temperature profile within the Reactor. In addition the linear moisture spray is an effective method to control temperature spikes when transitioning from oxidizing to reducing conditions and vice versa as occurs during the flash calcination of activated carbon. The moisture injection can be air atomized water or steam. The injection moisture can also contain halide salts, alkali solutions, or other chemical additives beneficial to the product being calcined. The injection spray pattern angle for the linear spray relative to the linear Reactor flow is of critical importance since an excessively wide spray pattern will make premature contact with the carbonaceous feed causing feed material to drop out of cyclonic conveying suspension. An excessively narrow spray stream pattern may not properly mix within the Reactor in the desired range. Without being limiting the preferred moisture injection spray pattern angle is between 10 and 30 degrees with 20 degrees relative to the burner face plane is considered optimal. It is understood to those skilled in the art that the moisture injection spray lance(s) can penetrate into the burner flame area prior to material injection at various angles or straight as required to locate the spray lance(s) to the correct positions near the center of the Reactor flow. The tip(s) of the spray lance(s) can be designed to correct for the penetration angle such that the tip(s) are angled to point down the relative center line of the Reactor. Mounted on the tip(s) are nozzle(s) designed to spray at the desired spray pattern angle. The key principle is the injection of moisture down the Reactor centerline such that the moisture enters the Reactor well prior to the carbonaceous feed material tangential injection yet sprays at a deliberate angle such that the moisture does not interact with the feed material until after cyclonic and linear flow of the material has been established.

12. Another key factor is the ratio of the total moisture from all sources (i.e., from products of combustion, feed moisture, injected moisture, flue gas recirculation, etc) to the carbonaceous feed (dry basis). This ratio should be a minimum of 1.1 lb moisture per lb carbonaceous feed (dry basis) with 1.5 to 2 lbs moisture per lb

of carbonaceous feed (dry basis) being more ideally suited for many carbonaceous feed materials.

13. The design of the Reaction Chamber, which again is defined as the vessel(s) from carbonaceous feed injection through to the product disengagement and separation from reaction gases, must create an oxidizing environment transitioning to a reducing environment. For many precursor materials the initial oxidizing environment prior to transitioning to a reducing environment can be beneficial as a pretreatment of the feed material surface area immediately prior to activation as an additional means to control adverse reactions. When utilizing Single Stage Activated Carbon Production in a single Reaction Vessel, devolatilization occurs in an oxidizing transitioning to a reducing environment and the activation occurs in primarily a reducing gas environment. To assist in creating distinct regions additional gases such as air, re-circulated flue gas, and/or moisture can be added at various points along the gaseous flow path of the Reaction Vessel thereby creating distinct reaction zones within the Reaction Vessel. When utilizing Dual Stage Activated Carbon Production in multiple Reaction Vessels, activation occurs in an oxidizing transitioning to a reducing environment in a single Reaction Vessel. The devolatilization occurs in primarily a reducing gas environment in a separate Reaction Vessel which utilizes the separated flue gases from the first Reaction Vessel as the heat source. To assist in creating distinct regions when utilizing Dual Stage Activated Carbon Production additional gases such as air, re-circulated flue gas, and/or moisture can be added at various points along the gaseous flow path of either or both of the Reaction Vessels.

14. When starting up and shutting down the system, a method is required that can rapidly control temperature spikes in the activating region of the Reaction Vessel during transition from oxidizing to reducing conditions and vice versa. On start up the temperature spike is caused by excessive carbonaceous feed combustion until excess oxygen is depleted. Upon shut-down temperature spike occurs due to hot residual carbon in the Reaction Vessels burning when excess oxygen becomes available.

15. Moreover, by including a co-product industrial mineral to be calcined, such as magnesium, trona, or calcium carbonate, a calcination product (e.g., lime) can be produced simultaneously with the activated carbon and can further be a source of temperature control due to the endothermic nature of calcination. The co-produced or co-product industrial minerals are defined as minerals that are capable of undergoing calcination under the same operating conditions as the carbon being heat treated and that represents at least 50% of the heat-treatment system output in terms of quantity. So, for example, limestone is introduced with the carbon being heat treated in sufficient quantity that it results in at least 50% of the output (in the form of lime) in addition to activated char. Thus, co-product industrial minerals are to be distinguished from mere "enhancers," which are added to the system but do not result in a separate "co-product" in any appreciable amounts (and certainly not over 50% of the system output of products). For example, adding a bromide dopant to the carbon would be considered a an enhancer and not a co-product industrial mineral because mainly brominated carbon results, with no other "co-product" making up at least 50% of the system output of products. Of course, the co-product industrial minerals can add to the effectiveness of the AC. For example the removal of sulfur in coal power plant flue gases with lime can benefit the ability of AC to adsorb mercury. Another example is the industrial mineral commonly referred to as trona where when co-calcined with AC can benefit the mercury adsorption by not only removing sulfur compounds but by also adsorbing mercury in the trona pore structure created during calcination.

16. Moreover by including a metallic mineral, oxides, or salts such as iron compounds, nickel compounds, or other mineral compounds a slightly magnetic or paramagnetic AC can be produced which may be beneficial for separation of spent AC from fly ash when the AC is used for mercury control in coal fired power plants.

17. Furthermore, this method of AC production lends itself to pre-activation halide compound treatments, such as bromination. This treatment can occur in several

ways such as the premixing of halide salts such as sodium bromide, calcium bromine or iron bromide or a combination of halides with the carbon precursor material resulting in the concurrent activation and halide treatment of the AC. Due to the thermal treatment conditions, the concurrent activation and halogenation of the carbon precursor can have a positive impact on the effectiveness of the halogenation of the activated carbon.

18. Additionally, another unique method of AC halogenation can be utilized when flash activated AC has been produced concurrently or simultaneously with an industrial mineral such as calcium oxide as previously described or has been pre-mixed with a metallic mineral, oxide or salt or a combination of two or more of these compounds. This method reacts the co-product AC with a halide acid resulting in a halogenated product consisting of halide salt(s) (i.e. Calcium bromide, iron bromides). Some halide salt enhanced AC products can have paramagnetic properties which may be beneficial when magnetic separation of the spent enhanced AC from ash by-products is desired. An example of a potential use of magnetic separation could occur when enhanced AC is used for mercury removal from coal fired power plants.

19. Another valuable feature of the technology is the ability to classify the calcined product in conjunction with separating the particulate calcined product from the hot calcination gas stream. A high temperature cyclone is employed to separate calcined particulate product and the hot calcination gases. The high temperature cyclone can be engineered to perform within an efficiency range often in excess of 98% collection efficiency. Cyclones preferentially collect coarser material at higher efficiencies than finer fraction material. It can be very desirable to collect less than the maximum collection efficiency percentage if the uncollected percentage is undesirable product. For example in the production of activated carbon the finest fraction of product contains the highest ash content due to excessive activation conditions on the high surface area of the fine particles. Designing the particulate separating equipment to collect and partially classify the product at lower than optimal collection efficiencies can greatly improve the quality of the calcined material. Activated carbon product produced by this

method of flash calcination has shown a significant increase in ash percentage for calcined material finer than 200 mesh. As previously stated cyclones preferentially collect coarser material. Operating the cyclone in a manner to favor varying degrees of cyclone particulate carryover allows the finer fraction of the calcined material to be separated to an extent from the higher-quality coarser material. Thus, a method has been developed of on-the-fly classifying of activated carbon during treatment in a heating system containing a Reactor and a cyclone by adjusting the collection efficiency of the cyclone downwardly during production of the activated carbon. The cyclone efficiency can be lessen by adjusting flow conditions, such as dropping the pressure within the system. The desired amount of carryover will vary depending on the product characteristics of the material being calcined. Continuing the example using activated carbon it is common for roughly of 5% of the product produced utilizing this method of flash calcination to be predominantly ash in composition. As an example operating the cyclone with about 95% collection efficiency and not greater will classify a significant portion of the undesirable high percentage ash carbon out of the product activated carbon. Alternately other high temperature classification methods (similar to air classification) can also be utilized in place of a high temperature cyclone to both collect the calcined product and to classify or separate out the undesirable finer fraction. This method is unique in that proper conditions for activation reactions and product classification can occur within the same Reaction Vessel.

[0019] Overall there is a need for a process that can significantly reduce the capital cost requirements for AC production and processing and that is inherently stable, easily adjustable, and precisely repeatable.

[0020] Additional features and advantages of the invention will be forthcoming from the following detailed description of certain preferred embodiments when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. 1 schematically illustrates an activation system (for example, a calcining plant) of the prior art.

[0022] FIG. 2 illustrates an overview flow diagram of a system and methods according to the invention.

[0023] FIG. 3 illustrates a flow diagram of a single-stage method according to the invention.

[0024] FIG. 4 illustrates a flow diagram of a dual-stage method according to the invention.

[0025] FIG. 5 schematically depicts a first system embodiment of the invention.

[0026] FIG. 6 schematically depicts a second system embodiment of the invention.

[0027] FIG. 7 schematically depicts a third system embodiment of the invention.

[0028] FIG. 8 schematically depicts in a cut-away section (A) a first burner embodiment featuring moisture spray injection.

[0029] FIG. 9 schematically depicts in a cut-away section (B) a second burner embodiment featuring moisture spray injection and buffering gas flows.

[0030] FIG. 10 schematically depicts in a cut-away section (C) a third burner embodiment featuring moisture spray injection and buffering gas flows.

[0031] FIG. 11 depicts activated carbon ash percentage by particle size.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0032] Processes according to the invention can be divided into the following main categories: 1) Carbonaceous feed material (feedstock) preparation, 2) Calcination or other heat treatment, 3) Activation, 4) Post activation treatment, 5) Process gas conditioning, 6) Optional AC enhancement practices, 7) Additional AC enhancement practices, 8) Reaction Chamber moisture spray and tangential port options, 9) Buffering Gas method, 10) Additional buffering gas method, and 11) Activated carbon ash percentage by size. The calcining stage can accomplish both devolatilization and subsequent activation reactions of carbonaceous feed material in a single Reaction Vessel (Single-Stage Activated Carbon Production) or in two separate Reaction Vessels (Dual-Stage Activated Carbon Production). Each of the following sections corresponds to the Process Block Flow Diagram of Fig. 2 (with the same numbers indicating like parts/processes in Figs. 3-10).

Carbonaceous Feed Material Preparation 10a-10d

[0033] A first embodiment of the invention can produce a combination of granular and pulverized AC utilizing a variety carbonaceous feed stock material. A blend of carbonaceous materials can also be created to tailor the properties of the AC. Materials that can be used include coal, biomass, and petroleum based material. The type of feed material utilized depends on the intended use of the AC since each material produces or has unique adsorption characteristics. For example, lignite coals when activated produces an AC with excellent vapor phase mercury adsorption characteristics; while a biomass such as coconut shells produce an AC with some of the highest overall adsorption capabilities.

[0034] Preparation of the feed material 10b varies depending on feed stock and the desired end product. Generally, the inventor's activation technology has shown that producing a more granular AC is the most effective since a good quality product can be produced and the AC can be further ground if necessary. Therefore even though the process does not require exclusively granular feed to produce AC, process advantages and product quality do indicate that the highest quality AC can be produced using granular feed with a defined feed size distribution. Moreover, feedstock granules of at

least 170 mesh or greater in size is best. A typical feed preparation for lignite coal would include primary crushing followed by subsequent roll crushing to minus 10 mesh. Roll crushing is often preferred over other crushing methods since it produces the least amount of fines. Crushed material can be screened with the oversized material being re-circulated to the mill if required. Material substantially finer than 120 mesh can be processed separately to produce an AC with different characteristics. Prepared feed material is stored in a silo or hopper. Moisture in the carbonaceous feed material 10a can also be beneficial to help buffer the carbonaceous feed material from various adverse early reaction conditions in the Reaction Vessel 14a and/or 15a due to excessive initial Reaction Vessel temperatures. Free moisture content of the carbonaceous material will be limited by the particle size and flow characteristics of the feed material. Sized feed material 10b must remain free flowing to properly feed, convey, and disperse into the Reaction Chamber cyclonic flow.

[0035] Fine feed material of less than 120 mesh tends to devolatilize and activate significantly faster than coarser granular feed resulting in fines being over activated or gasified resulting in not only product loss but increased residual ash. The gasification of fines also leads to excessive loss of activating gases thereby diminishing the quality of remaining AC particulates. Further compounding these issues is the loss in efficiency and process capacity. In general every pound of carbon gasified or carried out of the system increases the flue gas conditioning required. This increased gas conditioning requirement further reduces plant production capacity. As a rule every pound lost through carry over or excessive gasification may result in much more than a pound of lost production capacity.

[0036] The hopper or silo 10c preferably is a mass flow type that refers to a hopper in which the first product in will be the first product out. This hopper acts as a receiver for prepared carbonaceous feed material that is to be carefully metered to the calciner. The hopper provides surge capacity for constant, uninterrupted material feed to the calciner. As the hopper level lowers, the carbonaceous feed from the grinding circuit is proportionally increased and vice versa. This allows grinding circuit to run intermittently and provides time for maintenance. The material being discharged and metered from the hopper is introduced into a pneumatic conveying line and conveyed to

the calciner Reaction Chamber. Of course, a calciner is used as an example activation system, and the methods of the invention can be practiced in other systems suitable for heating a particulate carbon feedstock to form an activated carbon as herein described.

[0037] In situations where gas or fuel oil is not available for the Reaction Vessel multi-fuel burner 14b or are limited either for economical or logistical reasons and when coal is utilized as the carbonaceous feed it is possible to divert a portion of the carbonaceous feed 10d and prepare it for use as a primary or secondary fuel in the multi-fuel burner 14b.

[0038] Another method for controlling carbonaceous feed size distribution as well as further increasing the quality of the activated carbon produced and improving operational efficiencies involves sizing 10b, i.e., separating the finest fraction of carbonaceous feedstock material prior to calcination. The finest fraction can be defined as the finest 15 percent or less of the carbonaceous feedstock material. This finest fraction is specifically meant to include feed material finer than 170 mesh. The finest fraction of the carbonaceous feedstock material competes with the coarser fractions for activating gases. The finest fraction has the highest surface area and therefore more readily reacts with the activating gases to the point where such particles excessively activate or gasify. This improves product quality by lowering the amount of fines in the carbonaceous feedstock material thereby tightening the feed size distribution thus facilitating more uniform calcination. Once removed this finer fraction of carbonaceous feedstock material can ideally be pulverized as part of feed sizing 10b and utilized as a solid fuel for the burner. The combustion in the burner 14b of the finest fraction of the carbonaceous feedstock material is beneficial in lowering the operating cost of calcination by providing a significant portion of the heat required for calcination. Combustion of the pulverized fines through the burner 14b provides nearly complete combustion of the finest fraction of carbonaceous material. The resultant ash byproduct of this combustion is exceedingly fine and will represent a higher fraction of the cyclone carryover particulates thus helping to separate a significant portion of the ash generated from the solid fuel burner 14b from the activated carbon product 20.

Conveying Gas and Blowers 11

[0039] A conveying air/gas blower(s) 11, which can include air, re-circulated flue gases (FGR), other gases or a combination, can be utilized to convey the carbon feedstock to the Reaction Vessels(s) 14a and/or 15a. The carbon feedstock can be also mechanically conveyed to the Reaction Vessels(s) and mixed immediately upon entering the Reaction Vessels(s) with a cyclonic flow of air, FGR, other gases or a combination, that were previously or concurrently introduced into the Reaction Vessels(s), thereby creating the desired cyclonic feed material flow pattern.

Activated Carbon Enhancers and/or Simultaneous Co-product Production 12, 17b and 20

[0040] One aspect of the invention is the simultaneous production of activated carbon with other industrial minerals, metallic minerals, oxides, and salts to produce an "enhanced AC" (EAC). This simultaneous production of various materials followed in some cases by additional acid or base treatment creates a ready to use multi-functional EAC blend with unique characteristics such as SO_2 removal, paramagnetic properties, halogenation, or EAC with low foaming indexes to name a few examples. The presence of many of these co-products during activation can also in some cases enhance the physical AC pore size distribution and adsorption properties. Alternately, the co-product feed and the carbonaceous feed can be mechanically premixed and metered to the system from the same feed location.

[0041] The inventor has separated the enhancement of AC using flash activation into three basic categories:

[0042] The first category is the simultaneous or co-produced AC products where each component could be produced separately using flash calcination but are produced concurrently. The co-product AC production includes industrial minerals such as lime, trona, alumina, and clay. One example of a simultaneously produced co-product AC is calcium oxide (lime) and activated carbon. The inventor's technology was initially developed for the calcination of industrial minerals such as lime, trona, alumina, and clay, with lime being the most thoroughly developed. The utilization of flash activation

to simultaneously calcine lime and devolatilize and activate AC has proven very effective. Such a product is suitable for SO_2 and Hg removal in power plants.

[0043] The second category includes additives to the carbonaceous feed material to enhance the AC during activation but that would not typically be flash calcined by themselves. These include metallic minerals, oxides and salts. An example of this would be the addition of sodium bromide to the carbonaceous feed material and flash activating the mixture to produce a well halogenated AC with numerous enhanced characteristics derived from the concurrent activation and halogenation of the AC. Halogenated AC is most often utilized for its ability to oxidize vapor phase contaminates such as elemental mercury from coal fired power plant flue gas emissions. Another example of this second category is the addition of metallic metals or oxides to the carbonaceous feed material. This mixture when heated at activation temperatures and under activation conditions can produce a uniformed metal rich AC which can serve as a catalyst or as a precursor for additional AC treatment. Such an AC product can be engineered to be magnetic or paramagnetic.

[0044] The third category is the post treatment of AC produced under either of the first two categories using an acid or base or a combination. An example of this is the reaction of lime enhanced AC with hydrobromic acid producing a halogenated (calcium bromide) enhanced AC. Another example of this third category is the treatment of an iron enriched AC with hydrobromic acid to produce a halogenated (iron (II or III) bromide) AC with paramagnetic properties.

Introducing Carbonaceous Feed to the Process Mixed with A Buffering Gas, e.g., Flue Gas Recirculation (FGR) 13a-13b

[0045] A buffering gas 13a, e.g. re-circulated flue gases (FGR), may also be mixed with the blower 11 or preferentially injected directly into the Reaction Chamber 35 to help provide additional gas flow required for proper cyclonic rotational flow velocity and flow profile within Reaction Chamber 35. This enables independent control of buffering gas 13a rate without affecting material feed conveying. As previously stated this buffering gas 13a can be introduced into the Reaction Chamber 35 separately from blower 11 and at injection locations 51 preceding the injection points 50 of blower 11

such that buffering gas 13a flow patterns are well-established prior to the injection of blower 11 flows (see Figs. 8-10, for example). The separate and earlier injection 51 of buffering gas 13a provides additional buffering between the hot combustion gases 52 and the carbonaceous feed material 10b at the injection inlet 50 and associated feed convey means flow zone 50a by creating a zone 51a of buffering gases around the circumference of the hot combustion gases 52. This zone 51a remains relatively free of carbonaceous feed material during the first milliseconds to seconds of calcination. The buffering gas is an excellent source of activating gases due to its high moisture and significant amounts of CO_2 along with favorable low amounts of O_2. Since the presence of excess oxygen consumes carbon the utilization of buffering gases 13a can help suppress early combustion reactions.

[0046] Moisture 13b and other aspects of the buffering gas 13a, e.g., FGR, such as the gas composition can be adjusted by adding moisture, air or other gas sources to the buffering gas 13a. This allows the operator to change and control the heating environment such that a wide variety of reaction conditions and products is achievable. This also provides the carbonaceous feed material with an additional buffer against early peak flame temperatures and adverse reactions encountered during the initial injection.

[0047] The carbon feedstock 10b can be conveyed to the Reaction Chamber 35 using conveying air/gas blower 11, buffering gases 13a, other gases or a combination, mixed prior to or upon entering the Reaction Chamber 35 (also applicable to Reaction Vessel 14a as shown by box 13c in Fig. 2) to convey the carbon feedstock to the Reaction Vessel. Although pneumatic conveying 11 is the preferred method of introducing the carbonaceous feed material into the Reaction Vessel, feed material can also be mechanically conveyed to the Reaction Vessel and mixed immediately upon entering the Reaction Vessel with a flow of air, buffering gases, other gases or a combination, from blower 11, buffering gases 13a and/or 13b that were either previously or concurrently introduced into the Reaction Vessel thereby creating the desired cyclonic feed material flow pattern and composition.

[0048] In addition, as previously mentioned, moisture in the carbonaceous feed material 10a can also be beneficial to help protect the carbonaceous feed from adverse early reactions. High moisture yet free flowing carbonaceous feed will be beneficial whether using buffering gases, air, other gases, or a combination to create and maintain the cyclonic feed material flow.

[0049] Another key factor for rapidly controlling calcination conditions is the injection of moisture 14e through the center portion of the burner 14b hot combustion gases 52 down the linear length of the Reaction Chamber 35 through one or more spray lances 14e. This moisture injection occurs prior to the conveying gas 11 injection port 50 for the carbonaceous feed material 10b into the Reaction Chamber 35 but only contacts or mixes with the carbonaceous feed material 10b and conveying gas 11 after the carbonaceous feed material cyclonic flow zone pattern 50a and linear flow has been established with at least one full revolution. The cyclonic flow pattern is generally considered established one half of the Reaction Chamber 35 diameter downstream from the carbonaceous feed injection 50. This linear injection of moisture 14e is useful in further tempering peak flame temperatures of the hot combustion gases 52 and providing moisture evenly for downstream calcination processes such as activated carbon. The moisture injection 14e can also be utilized to modify the reaction temperature profile within the Reaction Chamber 35. In addition the linear moisture spray 14e is an effective method to control temperature spikes when transitioning from oxidizing to reducing conditions and vice versa as occurs during the flash calcination of activated carbon. The moisture injection 14e can be air atomized water or steam. The injection moisture 14e can also contain halide salts, alkali solutions, or other chemical additives beneficial to the product being calcined. The injection spray pattern angle for the linear spray 14e relative to the linear Reactor flow is of critical importance since an excessively wide spray pattern will make premature contact with the carbonaceous feed causing feed material to drop out of cyclonic conveying suspension. An excessively narrow spray stream pattern may not properly mix within the Reactor in the desired range. Without being limiting the preferred moisture injection spray pattern angle is between 10 and 30 degrees with 20 degrees relative to the burner face plane 54b of the burner baffle area 54a is considered optimal. It is understood to those skilled in the art that the moisture injection spray

lance(s) 14e can penetrate into the burner flame area prior to material injection at various angles 55 or straight 54 as required to locate the spray lance(s) 14e to the correct positions near the center of the Reactor flow. The tip(s) of the spray lance(s) 55 can be designed to correct for the penetration angle such that the tip(s) are angled to point down the relative center line of the Reactor. Mounted on the tip(s) are nozzle(s) designed to spray at the desired spray pattern angle. The key principle is the injection of moisture down the Reaction Chamber 35 centerline such that the moisture 14e enters the Reactor well prior to the carbonaceous feed material 10b tangential injection port 50 yet sprays at a deliberate angle such that the moisture 14e does not interact with the conveying gases and/or carbonaceous feed material flow zone 50a until after cyclonic and linear flow of the material has been established.

[0050] The flow rate of 11, 13a and 13b provide a substantial portion of the motive force required to create the cyclonic flow within Reaction Chamber 35. In addition burner 14b can also be designed to impart rotational momentum to assist in the creation of cyclonic flow within the Reactor. The cyclonic flow in the Reaction Chamber 35 in conjunction with the feed conveying gas and or buffering gas composition creates a more uniformed AC product by buffering the carbonaceous feed from excessive Reaction Vessel temperatures caused by the burner flame and/or from excessive partial combustion of the feed. This is due to centrifugal forces acting on the particles in such a manner that they travel in close proximity to the Reaction Chamber walls 35. This allows a more gradual blending of feed material and hot burner combustion gases thereby improving the yield and carbon pore structure development. The cyclonic flow also enables the Reaction Chamber 35 to retain the coarser feed material longer than the finer material. Cyclonic gas flow rotational velocities within the Reaction Chamber 35 preferably should be a minimum of about 90 RPM average rotational velocity and more ideally in the 120 to 240 RPM range in the "burn" or oxidation zone of the Reaction Chamber. By utilizing this method, adverse carbon particle surface reactions, ash fusion, excessive gasification and product loss is avoided. In addition cyclonic flow in the Reaction Chamber increases particulate retention time by creating a helical material flow pattern thereby increasing the particle path length

[0051] The maximum rotational velocity will vary with Reactor vessel geometry and carbonaceous feed material characteristics. Excessive rotational velocities may lead to particulate attrition and thereby generate fractions of finer carbonaceous material. The results of finer fractions would be the same as if a wider feed particle size distribution were utilized. As previously stated, in most cases the finer feed will experience excessive activation or gasification resulting in product loss while the more granular feed will experience a lesser degree of activation leading to a reduction in product quality. Tangential particulate rotational velocity in the vertical portion of the Reaction Chamber is further defined as ranging from 1 to 8 revolutions per second at the entrance to the Reactor to 0.5 to 4 revolutions per second at the exit of the Reactor.

[0052] The Reaction Chamber 35 has both oxidizing and reducing conditions in which devolatilization and activation predominately occur in distinct regions of the Reaction Vessel. The control of the cyclonic gas flow rate, moisture percentage, and/or activation content can change the oxidizing to reducing transition profile. These in turn also affect the cyclonic rotational speed, reaction time, temperature, oxidizing and reducing conditions, and other aspects of the devolatilization and activation process. Therefore the air and gas flows from 11, 13a and/or 13b are critical for generating optimal Reaction Chamber 35 flow conditions

[0053] The Reaction Chamber 35 typically includes both vertical and horizontal vessels and ductwork. The minimum linear conveying velocity required in the vertical portion of the Reactor depends on the carbonaceous feed size and other characteristics. In general the linear velocity should be no less than 35 feet per second. The minimum velocity in the vertical portion of the Reaction Vessel is called the chocking velocity. The minimum velocity required to maintain particulate conveying in the horizontal portion of the Reaction Vessel is called the saltation velocity. Due to the fact that it is more difficult to maintain pneumatic conveying in a horizontal vessel than in a vertical vessel, the saltation velocity is greater than the choking velocity. This means that the minimum Reaction Vessel conveying velocity is limited by the saltation velocity. In order to lower the saltation velocity requirements the present invention achieves a significant reduction in the minimum velocity required by angling downward the horizontal ductwork portions of the Reaction Vessel. A downward angle of 15 degrees

or greater is enough to significantly reduce the minimum velocity requirements to avoid saltation. This also allows the vertical and horizontal portions of the Reaction Vessel to have closer minimum velocity requirements.

Single Stage Activated Carbon Production 14a-14e

[0054] The Reaction Vessel 14a is the heart of a pneumatic flash calciner (PFC). As previously mentioned, the calcination of carbonaceous material to produce AC can be classified as two distinct steps. The first step is generally considered devolatilization where moisture and volatile carbonaceous compounds are driven out of the feed material particulates. The second step is the activation of the remaining carbon char particulates using an activating gas such as H_2O, CO_2, and/or O_2. As previously stated, though these steps imply that devolatilization and activation are separate reactions they do in reality overlap to a large degree depending on process conditions. A portion of the carbonaceous feed is invariably activated during devolatilization. Likewise a portion of the carbonaceous feed is further or more completely devolatilized during activation.

The activation reactions include but are not limited to the following;

Primary activation reaction examples:

$C+H_2O >> CO+H_2$

$C+CO_2 >> 2CO$

$C+O_2 >> CO_2$

Secondary activation reaction examples:

$CO+H_2O >> CO_2+H_2$

$2CO + O_2 >> 2CO_2$

[0055] An aspect of the invention is a unique stand alone production method for producing AC that utilizes rapid devolatilization in a conditioned high temperature gaseous environment suitable for immediately subsequent and/or concurrent carbon activation. This is referred to as "Single-Stage" AC production.

[0056] During the stage, portions of the carbonaceous feed undergo devolatilization while other devolatilized portions of the particulate material are advancing to be

activated. This enables the particulate feed material to devolatilize and activated in rapid succession. The retention time required for complete devolatilization/activation is temperature and pressure dependant but can generally be accomplished within two to fifteen seconds. The temperature required again depends on the type of carbonaceous feed material utilized but in general ranges from between 1200 and 2100 degrees Fahrenheit. The Reaction Vessel is operated under oxidizing transitioning to reducing conditions to maximize AC yield and production rates. The pressure is generally maintained near atmospheric conditions. Also, the heat generated through the burner 14b should be between 4,000 to 10,000 BTU per pound of activated carbon.

[0057] The main calcine Reaction Chamber 35 is generally a vertical, round, open chamber fitted with a centrally mounted vertically oriented burner 14b. The burner provides the heat input necessary for calcining. The burner is fired under stable oxidizing conditions with gas/oil or coal fuels. Reducing conditions in the calciner Reaction Vessel occur when the carbonaceous feed material consumes the remaining excess air thereby creating an oxygen deprived environment. The main reasons the burner 14b is operated under oxidizing conditions is to promote stable operation and to ensure that the AC produced is not excessively contaminated with carbon from the burner fuel sources which have been exposed to substantially different conditions. Operating the Reaction Vessel to transition and operate under reducing (oxygen depleted), activation favorable (CO_2 and moisture laden gases), conditions requires the produced AC to be separated from the activating gases at elevated temperatures. The reducing conditions also require the separated gases to be subsequently oxidized to destroy the resulting CO and other volatile gases. Flue gas recirculation 14c can also be utilized with the burner from several sources such as after the flue gases has been oxidized to help control burner flame temperatures. Alternatively FGR can be supplied via 14c from after the Reaction Vessels 14a or 15a still having considerable amounts of combustible gases available to lower the fuel requirements of the burner 14b. Cooling of the gases from 14c with an indirect heat exchanger may be required to safely transport the gases back into 14b.

[0058] As described above, the preferred method for introducing feed material into the Reaction Chamber 35 is to convey the material pneumatically. The feed material

from the metering feeder at the bottom of the feed hopper(s) 10c is conveyed with air and mixed with a mixture of a conveying gas 11 and a buffering gas 13a (e.g., re-circulated flue gases, a.k.a. flue gas recirculation (FGR)). This pneumatic stream is introduced into the calciner tangentially at either a single point or multiple points (e.g., Fig 8 at inlets 50). The buffering gas such as FGR enhances the conditions required for good activation by providing the Reaction Vessel with additional H_2O and CO_2 required for activation As previously stated this buffering gas 13a can be introduced into the Reaction Chamber 35 separately from blower 11 and at injection locations 51 preceding the injection points 50 of blower 11 such that buffering gas 13a flow patterns are be well-established prior to the injection of blower 11 flows. The separate and earlier injection 51 of buffering gas 13a provides additional buffering between the hot combustion gases 52 and the carbonaceous feed material 10b at the injection inlet 50 and associated feed convey means flow zone 50a by creating a zone 51a of buffering gases around the circumference of the hot combustion gases 52. This zone 51a remains relatively free of carbonaceous feed material during the first milliseconds to seconds of calcination. The tangential injection produces or sustains a cyclonic upward flowing vortex. This vortex traveling vertically upward allows the material to act as a buffer between the Reaction Heating Chamber 35 walls and the extremely hot burner gases 52. As the material is conveyed vertically the Reaction Vessel gas temperature is lowered, and the material temperature is raised to the point of de-volatilization and activation. The vortex allows coarse material to be retained slightly longer than the finest, producing a more uniformed AC product. This process is capable of a wide turn down ratio and can utilize various fuels.

[0059] The Reaction Vessel 14a is equipped with supplemental air and/or moisture injection ports 14d at various points along the Reaction Vessel. These injection ports allow additional flexibility and control in maintaining flow profiles and for modifying oxidizing and reducing zone conditions. The design and operation of the system of the present invention is sufficiently flexible to be tailored to optimize the use of a specific type of feed and the production of specific AC products. Positioning and control over the air and/or moisture injection into the reaction vessel can be used to suppress coking and combustion reactions. For example, the location(s) of one or more air/moisture injection port(s) along the reaction vessel can be varied in order to extend or minimize

the oxidizing region within the reaction vessel. The greater flexibility enables well defined reaction regions in the Reaction Vessel 14a to be developed.

[0060] The Reaction Chamber 35 is equipped with linear moisture injection port(s) 14e through the center portion of the burner 14b hot combustion gases 52 which spray down the linear length of the Reaction Chamber 35 through one or more spray lances 14e. This moisture injection occurs prior to the conveying gas 11 injection port 50 for the carbonaceous feed material 10b into the Reaction Chamber 35 but only contacts or mixes with the carbonaceous feed material 10b and conveying gas 11 after the carbonaceous feed material cyclonic flow zone pattern 50a and linear flow has been established with at least one full revolution. The cyclonic flow pattern is generally considered established one half of the Reaction Chamber 35 diameter downstream from the carbonaceous feed injection 50.

[0061] The vertically oriented burner 14b is equipped with a cleanout mechanism on the bottom to allow for the continuous or intermittent removal of difficult to convey materials that have fallen out of the calcining pneumatic flow. The material discharged from the burner can either be discarded or conditioned and returned to the system. The temperature of the Reaction Vessel can be primarily controlled by the feed rate of the material. This means the higher the feed rate to the Reaction Vessel the lower the Reaction Vessel temperature and visa versa. This allows the burner to fire at near optimal conditions, and helps maintain gas flow consistency as well. The change in temperature is rapid when controlling with change in feed rate, and can change the temperature in a matter of a few seconds. Whereas, changing the temperature using air/ fuel ratios is much slower, requiring minutes and potentially leading to the system modulating. Reaction Vessel temperatures can also be primarily controlled using moisture injection after the system has achieved stable operation. The calciner materials of construction are designed for operating temperatures in the range of 2400° F and lower.

[0062] The material exits the top of the Reactor portion of the Reaction Vessel tangentially. The tangential outlet helps to sustain the vortex in the Reaction Vessel.

The material exiting tangentially travels through a downward sloping duct and enters a high temperature cyclone separator 36 portion of the Reaction Vessel. The tangential outlet helps improve the cyclone efficiency since the material is partially segregated from the gas flow as it travels along the outer wall of the Reactor portion of the Reaction Vessel and duct leading to cyclone 36. In the cyclone 36, temperatures are maintained at or above the minimum required activation temperature. It is important to separate the AC product from the gaseous products at elevated temperatures. This prevents the AC from picking up gaseous contaminates (that are adsorbable at lower temperatures) prior to AC discharge insuring a high quality product. Upon discharging the AC from the cyclone the material remains under reducing conditions.

[0063] As previously stated a high temperature cyclone 36 is employed to separate calcined particulate product and the hot calcination gases. The high temperature cyclone 36 can be engineered to operate as a product classifier in conjunction with the cyclone 36 primary function to efficiently separate calcined particulate product and the hot calcination gases. It can be very desirable to deliberately collect less than the maximum collection efficiency percentage if the uncollected percentage is undesirable product. For example in the production of activated carbon the finest fraction of product contains the highest ash content due to excessive activation conditions on the high surface area of the fine particles FIG 11. Designing the particulate separating equipment to collect and partially classify the product at lower than optimal collection efficiencies can greatly improve the quality of the calcined material 30a. Activated carbon product produced by this method of flash calcination has shown a significant increase in ash percentage for calcined material finer than 200 mesh. Alternately other high temperature classification methods (similar to air classification) can also be utilized in place of a high temperature cyclone to both collect the calcined product and to classify or separate out the undesirable finer fraction. The collected calcined product is thereby free of a substantial portion of the undesirable finer fraction and is discharged from the cyclone 36 portion of the Reactor Vessel 14a and into a surge hopper. This method is unique in that the proper conditions for activation reactions and product classification can occur within the same Reaction Vessel 14a.

[0064] During operation of the flash calciner, special considerations must be observed when transitioning from oxidizing conditions to reducing conditions and vice versa. A moisture injection system 14e is control looped to a temperature limit set point and is utilized to prevent system temperature from rapidly exceed high temperature limits under the described conditions.

[0065] When transitioning from oxidizing to reducing conditions, the increase in carbonaceous feed dramatically increases temperature until excess oxygen is consumed. After the excess oxygen is consumed, further increases in carbonaceous feed will lower temperature. Moisture will also buffer the temperature, thus allowing the system to remain at operating temperatures during transition. Alternatively, preheated combustion air can be bypassed in favor of ambient air thereby also reducing the process temperatures during transitions. Also FGR can be added in excess further helping to mitigate adverse combustion reactions associated with operating condition transitions.

[0066] When transitioning from reducing to oxidizing, residual carbon on the Reaction Vessel walls will immediately combust resulting in an undesired temperature spike. This will occur even if all feed and burner fuels are shut off as long as air continues to enter the system. Shutting all air, fuel and feed off will prevent much of the spike but will leave the system in a potentially combustible and hazardous state until cooled. The utilization of moisture injection 14e will again buffer the temperature during transition until residual carbon is consumed. Alternatively, preheated combustion air can be bypassed in favor of ambient air thereby also reducing the process temperatures during transitions. Also FGR either from 13a or 14c can be added in excess further helping to mitigate adverse combustion reactions associated with operating condition transitions.

[0067] For different carbonaceous feedstock material, Reaction Vessel exit gas composition can vary greatly depending on the carbonaceous feed characteristics. Other variables include the feed conveying gas composition and flow rate, combustion composition and flow rate, supplemental fuel rate, exit temperature and moisture injection rates. These variables are in practice adjusted based primarily on feed material characteristics, activated carbon product characteristics and exit gas composition. The

exit gas composition includes several gaseous chemical species. There are three gaseous species in particular whose relationship is of particular importance. These gaseous species include carbon monoxide (CO), carbon dioxide (CO_2), and hydrogen (H_2). The ratio between these species can serve to help determine the proper Reaction Vessel activation gas conditions. A novel ratio range has been found to exist between these species for the production of high quality activated carbon approximately as follows:

H_2 to CO Ratio in the range of 1:1 to 1.75:1

CO_2 to CO Ratio in the range of 1:1 to 2.25:1, and

CO_2 to H_2 Ratio in the range of 0.9:1 to 1.75:1

[0068] As mentioned above, in order to lower the saltation velocity requirements the present invention achieves a significant reduction in the minimum velocity required by angling downward the horizontal ductwork portions of the Reaction Vessel. A downward angle of 15 degrees or greater is enough to significantly reduce the minimum velocity requirements to avoid saltation. This also allows the vertical and horizontal portions of the Reaction Vessel to have closer minimum velocity requirements.

Dual Stage Activated Carbon Production 15a-15b

[0069] Staging the production of AC can in some cases be beneficial. Staging means that the carbonaceous feed is first de-volatilized in a flash calcination stream and then activated in a separate flash calcination stream. The stages can be completely separate calcination units with separate exhaust streams or the stages can be incorporated into one unit and operated in series.

[0070] A single AC production plant with two stages material would flow similar to the inventor's patented Pneumatic Flash Calciner (PFC) technology where the waste heat stream from one stage supplies the heat for the second stage (for example, see U.S. Patent 7,264,781). In this configuration the activation stage is the high temperature stage and the de-volatilization stage the lower temperature. The carbonaceous feed would enter the waste heat gas stream from the activation stage and subsequently devolatilize. The devolatilized carbon would then be feed into the activation stage. The activated carbon is then separated from the gas flows and discharged.

[0071] The dual stage process begins with the carbonaceous feed material 10b being conveyed pneumatically or mechanically into a devolatilization Reaction Vessel 15a. Pneumatic conveying of carbonaceous feed into the Reaction Vessel can utilize FGR gases as the conveying medium to help reduce carbon loss. Alternatively, ambient air can be utilized as the conveying air medium. Pneumatically introducing the feed into this Reaction Vessel is significant and very beneficial but not critical. The feed material enters this Reaction Vessel, which also carries process gases from the calciner Reaction Vessel 14a that still has considerable waste heat available. The material is dispersed into the gas flow that has sufficient heat available from the preceding activation stage to devolatilize the carbonaceous feed. The process gas stream remains deprived of oxygen which helps to reduce carbon loss and devolatilized char and gases are conveyed pneumatically into a cyclone separator. In the cyclone 36, the gases and solids are separated with less than the maximum collection efficiency percentage to collect and partially classify the carbon product. The collected calcined product is thereby free of a substantial portion of the undesirable finer fraction and is discharged from the cyclone 36 portion of the Reactor Vessel 14a and into a surge hopper. The separated gases continue to the process gas treatment portion of the process. The surge bin acts as a receiver for devolatilized carbon feed material that is to be carefully metered to the activation Reaction Vessel 14a. The surge bin provides surge capacity for constant, uninterrupted material feed to the calciner Reaction Vessel. Feed material discharges from the bottom of the surge bin through a high temperature variable speed airlock.

[0072] The level in the surge bin is maintained by adjusting the carbonaceous feed rate from the primary feed hopper 10c at the beginning of the process. As the level lowers, the feed is proportionally increased and vice versa. This helps maintain a constant load on the system and avoids the problems associated with keeping the system balanced. The level monitoring method can be a direct contact type level indicator or the surge bin can be located on load cells. The surge bin is constructed out of materials designed to handle reducing gases and materials in excess of 1200° F.

[0073] The surge bin is also equipped to be able to return a portion of dried material to an upstream feed back-mixer if required to enable back mixing with the raw feed to

dry the feed sufficiently to produce a free flowing feed product. The amount of back mixing, if required, will depend on the initial moisture content of the feed.

[0074] The devolatilized char is then metered into a pneumatic convey line 15b containing FGR gases to prevent char oxidation. Also, solid, liquid, and/or gas additives can be introduced at this point, i.e., after devolatilization and prior to activation. The char is then introduced tangentially into the activation Reaction Vessel 14a that is the same calcining Reaction Vessel described above. This vessel operates in the same manners as described above with the exception of the fact that the devolatilization reactions have already been substantially completed. The AC discharge and product handling remain the same regardless of whether a single stage or multiple devolatilization and activation process is chosen.

[0075] As previously mentioned dual stage production can also be accomplished using two separate flash calciners operating a different temperatures. One unit would produce devolatilized char and would then feed the other calciner Reaction Vessel that would activate the char to produce AC. Though considerably less efficient, this method could allow each stage to have separate emissions control equipment and differing process rates. Also as previously mentioned, in order to lower the saltation velocity requirements the present invention achieves a significant reduction in the minimum velocity required by angling downward the horizontal ductwork portions of the Reaction Vessel. A downward angle of 15 degrees or greater is enough to significantly reduce the minimum velocity requirements to avoid saltation. This also allows the vertical and horizontal portions of the Reaction Vessel to have closer minimum velocity requirements.

Process Gas Treatment 16a-16j

[0076] The flue treatment generally involves the destruction and/or removal of regulated emissions as well as utilization or control of waste heat. While there are many ways to control and treat the flue gases, the inventive process typically uses the following control techniques. A thermal oxidizer (T.O.) vessel 16a is employed to complete combustion reactions such as H_2, CO, and Volatile Organic Compound (VOC's) created during the AC production process as well as control NOx through the

use of selective non-catalytic reduction (SNCR) technologies if required. This step can also be performed after dust collection with the use of externally heated thermal oxidizer or by employing the use of catalytic oxidation equipment. Typically, a T.O. positioned immediately following the AC production vessels is used. This location utilizes the high gas exit temperatures, in conjunction with a supplemental burner if required, to effectively oxidize the process gases with the addition of air 16b at proper oxidation temperatures. This minimizes the need for external heat and is therefore more efficient.

[0077] After process gases have been thermally oxidized they are cooled using a waste heat recovery boiler, a air to gas heat exchanger, or a direct spray cooler 16c depending on the site-specific requirements. The cooling medium 16d can be either air or water and is either vented or utilized in some manner such as a waste heat boiler. In the case of cooling by heat exchange with air a portion of the heated air 16e is utilized as preheated combustion air for the burner 14b.

[0078] In most cases depending on the feed material, site permit, and emissions limitation SO_2 abatement equipment 16f may be required. There are several viable options available such as lime base 16g or NaOH based SO_2 scrubbing systems. For the most stringent SO_2 removal requirements a spray dryer lime based scrubber is very effective and produces a dry waste stream. SO_2 removal efficiencies of over 90% are routinely achieved.

[0079] Dry particulate collectors otherwise known as dust collectors 16h or baghouses are used to remove remaining particulate matter. These systems are widely employed and have a proven reliability. Gas temperatures remain above the wet bulb temperature of the gas steam. The cloths to air ratios are generally in the range of 4 to 1 or less for long bag filter life. After the gases are filtered a portion of the gases are re-circulated either to for material conveying or for burner flame temperature control. Ash 16i collected from the dust collector contain fly ash and in the case of lime based scrubbing the ash contains significant amounts of CaSO3/CaSO4 and un-reacted Ca(OH)2.

[0080] After the dust collector the gases are drown through a system draft fan and are sent to the stack 16j. The height of the stack and diameter are functions of gas volumes and site requirements. All stacks include test ports and platforms with associated equipment.

Activated Carbon Product Cooling 17

[0081] AC production from the Reaction Vessel 14a is extremely hot and will readily combust or oxidize upon exposure to ambient air. To avoid this, the AC is cooled either indirectly 17a or by direct moisture injection quench 17b or both. The preferred AC cooling method, after AC activation treatment is completed, predominately utilizes indirect cooling. The hot AC is further cooled by pneumatic conveying 17c (as further described below) during pneumatic transport to product storage 19. To ensure that the product quality remains high the inventor favors the production of predominately granulated AC. This ensures that a minimal amount of surface area is inadvertently exposed to adverse conditions. Granular AC can be further processed and ground into pulverized AC if desired.

[0082] After cooling the AC it is either mechanically or pneumatically conveyed via means 17c to storage 19. Mechanical conveying includes screw conveyors, bucket elevators, etc. Pneumatic conveying can be accomplished with ambient air, dried air, or other gases. Since contact between hot AC and gases can alter the AC characteristic and quality, care must be taken to avoid accidental loss of quality.

Activated Carbon Product Post Process Surface Treatment 18

[0083] A means has been developed whereby hot AC can have its characteristics dramatically altered by using a hot AC direct quench with a pneumatic conveying gas 18 or air stream. This rapid quench changes the surface characteristics of the AC in various ways depending on the gas type, temperature, and retention time. This method is readily controllable and can by useful in producing AC with specific adsorption capabilities. Quenching hot AC with air, oxygen, nitrogen, water, argon, etc. can be utilized to change the surface characteristics of the AC. The pneumatic conveying gas or air blower 18a is normally a PD type blower and can be used with inert or reactive gases. The constant volume of a PD blower is helpful in maintaining process consistency and reproducibility.

Activated Carbon Product Storage 19

[0084] The conveyed activated carbon is stored in silos 19. These material silos can be used as final product silos or as intermediate storage. The recommended silos are mass flow type that refers to a type of silo where the first product entering the silo is the first product out thus ensuring that the inventory is constantly replenished.

Activated Carbon Product Size Specification Tailoring 20

[0085] After storing the AC in the storage silos, the AC can be further refined or treated 20. Such refining or treatment can include sizing, grinding, and chemical treatments. The final product AC can be sold in bulk or packaged as required.

Secondary Activation and Other Preconditioning and Treatment Methods 21-46

[0086] Furthermore, a secondary activation 21 may take place with or without newly introduced moisture or other additives, such a lignin or lignin compound. Such binders can improve granularity and other characteristics of AC.

[0087] Naturally occurring moisture levels for coal means the total internal and external water content of a given coal as it exists in the earth. Typical lignitic and subbituminous coals are received from the mine containing from about 15% to about 37% internal moisture and such coals usually lose significant moister upon exposure to ambient conditions due to mining, shipping, and sizing activities. It has been discovered that restoration of the naturally occurring moisture level (and not simply applying moisture to the exterior during processing) can improve activation of particulate coal. Of course, even coal from the same mine or area can have some variability in naturally occurring moisture levels. Thus, for a given load or sample of coal, the naturally occurring moisture level can be a value starting at the lower end of a range of values. For example, if a subbituminous coal from a mine has a naturally occurring moisture level of 20%-25%, at least 20% moisture content would be loaded into the coal prior to heat-induced activation. If there is high variability in moisture content, an average moisture content value may be used to determine the threshold amount of moisture to be loaded into the coal.

[0088] As illustrated in FIGs. 5-7, wherein like numerals indicate like elements, both methods and systems that enrich particulate coal with moisture up to and exceeding naturally occurring levels have been found to be advantageous. In FIG. 5, system and method for producing activated carbon from a particulate coal are depicted and herein described. Sized particulate coal 30 is loaded in to mixer 33 having mixing element 29. Within mixer 33, coal 30 is treated with an activation medium such as water through inlet 31. Optionally, a binder, co-product (e.g., lime), or other additive may also be introduced through inlet 32. The particulate coal feedstock 33 is loaded with an activation medium such that the water content of the feedstock is equal to or greater than that of the coal feedstock's naturally occurring state.

[0089] The moisture loading occurs at different rates depending on the particulate sizing. In general, the activation medium is provided and the particulate coal mixed for at least 30 seconds to ensure internal moisture content has increased to the desired level. Thus, for a typical lignite coal, this would equal roughly 30% to 37% moisture or greater (preferably, moisture does not exceed the point at which the coal is no longer flowable when pneumatically conveyed). The coal feedstock 30 is then conveyed to a heating system having a heat source (e.g., burner 34), Reaction Chamber 35, and cyclone 36. The feedstock 30 is at least partially activated in Reaction Chamber 35 and cyclone 36, where it is introduced tangentially and flows down to a mixing reactor 33a. Optionally, an air lock 38 can be utilized to isolate the mixing reactor 33a from cyclone 36. This isolation allows for the mixing reactor 33a to operate under different pressures and gaseous environments than that existing in cyclone 36. Gas 37 may be exhausted from cyclone 36.

[0090] As mentioned above, the heat treatment system may include a mixing reactor 33a within which the heat-treated carbon 30a discharged from cyclone 36 and formed from the particulate coal feedstock 30 may again be mixed with an activation medium and/or other additive(s) through inlets 31 and 32. An optional auxiliary burner 39 can be utilized with the mixing reactor to add additional heat, which, in turn, permits further use of an activation medium, enhancer or other additive and additional activation of the heat-treated carbon 30a. An exhaust vent 40 is present in the mixing reactor to allow for required ventilation.

[0091] The heat-treated carbon 30a next can be conveyed to an indirect cooler 41 having a mechanical conveyer, such as screw 41a. An indirect cooler is one in which the coolant does not directly contact the heat-treated carbon, thereby controlling further reactions. The mechanical conveyer is advantageous because of the high heat transfer accomplished by the conveyer's surfaces. From the indirect cooler 41, the AC product 42 can be dispensed and/or at least a portion can be re-circulated back through the heating system as indicated by arrow 43. Recirculation of AC product can increase the overall AC product surface area since the re-circulated portion experiences additional activation.

[0092] FIGs. 6 and 7 depict alternate configurations and methods in which particulate coal feedstock 30 is at least partially activated (thereby forming a heat-treated carbon 30a and eventually culminating in AC product 42) and then re-circulated through the heat treatment system (arrow 45 in FIG. 6 and arrow 46 in FIG. 7). As is further depicted in FIGs. 6 and 7, multiple stages of heating and activation medium, co-product, and/or enhancer treatment can occur. In one preferred embodiment, an enhancer is provided to the heat-treated carbon 30a (FIG. 7, through inlet 32). For example, hydrobromous acid may be added, thereby providing a unique path to bromination of a co-product such a lime.

[0093] In another preferred embodiment (FIG. 6), feedstock 30 is treated with an activation medium, co-product, and/or enhancer. Feedstock 30 is further conveyed to the ductwork connecting cyclone 36 and cyclone 44. Heat-treatment and at least partial activation occurs (thereby producing a heat-treated carbon 30a formed from the particulate coal feedstock 30) in the ductwork and cyclone 44. Heat-treated carbon 30a discharges from cyclone 44 into another mixing reactor 33a. Optionally, an air lock 38 can be utilized to isolate the mixing reactor 33a from cyclone 44. This isolation allows for the mixing reactor 33a to operate under different pressures and gaseous environments than that existing in cyclone 44. Gas 37 may be exhausted from cyclone 44.

[0094] As mentioned above, the heat treatment system may further include a mixing reactor 33a within which the heat-treated carbon 30a discharge from cyclone 44 may

again be mixed with an activation medium and/or other additive(s) through inlets 31 and 32. Heat-treated carbon 30a discharged from cyclone 44 retains significant heat, which, in turn, permits further use of an activation medium, enhancer or other additive and additional activation of the heat-treated carbon 30a. An exhaust vent 40 is present in the mixing reactor to allow for required ventilation.

[0095] The heat-treated carbon 30a is discharged from mixing reactor 33a and is then conveyed 45 to a heating system having a heat source (e.g., burner 34), Reaction Chamber 35, and cyclone 36. The heat-treated carbon 30a is again heat treated and further activated in Reaction Chamber 35 and cyclone 36, where it is introduced tangentially and flows down to a mixing reactor 33a. Optionally, an air lock 38 can be utilized to isolate the mixing reactor 33a from cyclone 36. This isolation allows for the mixing reactor 33a to operate under different pressures and gaseous environments than that existing in cyclone 36. Gases are exhausted from cyclone 36 where it communicates via ductwork to cyclone 44.

[0096] As mentioned above, the heat treatment system may include a mixing reactor 33a within which the heat-treated carbon 30a discharged from cyclone 36 may again be mixed with an activation medium and/or other additive(s) through inlets 31 and 32. An optional auxiliary burner 39 can be utilized with the mixing reactor to add additional heat, which, in turn, permits further use of an activation medium, enhancer or other additive and additional activation of the heat-treated carbon 30a. An exhaust vent 40 is present in the mixing reactor to allow for required ventilation.

[0097] Heat-treated carbon 30a upon discharge from mixing reactor 33a is conveyed to an indirect cooler 41 having a mechanical conveyer, such as screw 41a. An indirect cooler is one in which the coolant does not directly contact the heat-treated carbon, thereby controlling further reactions. The mechanical conveyer is advantageous because of the high heat transfer accomplished by the conveyer's surfaces. From the indirect cooler 41, the AC product 42 can be dispensed.

[0098] In another preferred embodiment (FIG. 7), feedstock 30 is treated with an activation medium, co-product, and/or enhancer. Feedstock 30 is further conveyed to a

heating system having a heat source (e.g., burner 34), Reaction Chamber 35, and cyclone 36. The feedstock 30 is at least partially activated in Reaction Chamber 35 and cyclone 36, where it is introduced tangentially and flows down to a mixing reactor 33a. Optionally, an air lock 38 can be utilized to isolate the mixing reactor 33a from cyclone 36. This isolation allows for the mixing reactor 33a to operate under different pressures and gaseous environments than that existing in cyclone 36. Gases are exhausted from cyclone 36 where it communicates via ductwork to cyclone 44.

[0099] As mentioned above, the heat treatment system may include a mixing reactor 33a within which the heat-treated carbon 30a discharged from cyclone 36 and formed from the particulate coal feedstock 30 may again be mixed with an activation medium and/or other additive(s) through inlets 31 and 32. Heat-treated carbon 30a discharged from cyclone 36 retains significant heat, which, in turn, permits further use of an activation medium, enhancer or other additive and additional activation of the heat-treated carbon 30a. An exhaust vent 40 is present in the mixing reactor to allow for required ventilation. Heat-treated carbon 30a upon discharge from mixing reactor 33a is conveyed 46 to the ductwork communicating cyclone 36 and cyclone 44. Further heat-treatment occurs in the ductwork and cyclone 44. Heat-treated carbon 30a discharges from cyclone 44 into another mixing reactor 33a. Optionally, an air lock 38 can be utilized to isolate the mixing reactor 33a from cyclone 44. This isolation allows for the mixing reactor 33a to operate under different pressures and gaseous environments than that existing in cyclone 44. Gas 37 may be exhausted from cyclone 44.

[00100] As mentioned above, the heat treatment system may further include a mixing reactor 33a within which the heat-treated carbon 30a discharge from cyclone 44 may again be mixed with an activation medium and/or other additive(s) through inlets 31 and 32. An optional auxiliary burner 39 can be utilized with the mixing reactor to add additional heat, which, in turn, permits further use of an activation medium, enhancer or other additive and additional activation of the heat-treated carbon 30a. An exhaust vent 40 is present in the mixing reactor to allow for required ventilation.

[00101] The heat-treated carbon 30a next can be conveyed to an indirect cooler 41 having a mechanical conveyer, such as screw 41a. An indirect cooler is one in which the

coolant does not directly contact the heat-treated carbon, thereby controlling further reactions. The mechanical conveyer is advantageous because of the high heat transfer accomplished by the conveyer's surfaces. From the indirect cooler 41, the AC product 42 can be dispensed.

[00102] A non-limiting example of a general operating mode is as follows: Feed material consisting of <20 mesh granular sub-bituminous coal with 22% moisture is used, with 90% of the feed material within 0.5 orders of magnitude in size. Using Single Stage Activated Carbon Production in a single Reaction Vessel. 65% of the gaseous mass flow passing through the burner includes combustion air, natural gas, FGR gases, and moisture. 35% of the gaseous mass flow entering the Reaction Vessel tangentially includes air, FGR gases, additional moisture, and carbonaceous feed material, with a ratio of total moisture to dry carbonaceous feed of greater than 1.1 to 1, a burner fuel BTU per lb of activated carbon of less than 8,000 BTU/lb AC, and operating at 1850 degrees Fahrenheit. The exit flue gases produced contain an approximate H_2 to CO ratio of 1.4 to 1, a CO_2 to CO ratio of 1.6 to 1, and a CO_2 to H_2 ratio of 1.1 to 1. The activated carbon produced has an Iodine number greater than 475 mg/g and a yield of 27.5%.

[00103] According to the foregoing, the invention has distinguishing features from other systems and methods. Along with a higher AC yield and the ability to process feedstock into a variety of treated carbons using the same heat-treatment system, process temperature can controlled using threshold amounts of coal and heat-treated carbon moisture. This allows the conveying gas flows to remain stable without the need to fluctuate other parameters such as combustion air, flue gas recirculation, and primary heat source fuel to adjust and maintain temperature.

[00104] By way of further example, Tables 1-3 below outline some trends toward improved AC processing and/or characteristics found by the inventor for certain parameters:

Table # 1 Surface Area/ Particle Size Distribution

Where at least 90% of the feedstock is within the referenced order of magnitude in size (in columns below) for particles coarser than 0.40mm

	1	0.75	0.65	0.5	<0.25
AC Surface Area	Poor	Marginal	Good	Better	Best

Where at least 90% of the feedstock is within the referenced order of magnitude in size (in columns below) for particles 0.40 mm or smaller in size

	1	0.75	0.5	0.25	0.2
AC Surface Area	Poor	Marginal	Good	Better	Best

Table # 2 Heat Required Through Burner / Yield %

Heat generated through the burner BTU/ per pound of activated carbon.

	2,000	4,000	6,000	8,000	10,000
AC Yield %	Poor	Marginal	Good	Better	Best

Table # 3 Surface Area / Total Moisture Ratio

Total Moisture from all sources to carbonaceous feed (lb total moisture to lb feed).

	<0.7 : 1	0.9 : 1	1.1 : 1	1.5 : 1	> or = 2 : 1
AC Surface Area	Poor	Marginal	Good	Better	Best

Various modifications are possible within the meaning and range of equivalence of the appended claims.

CLAIMS

1. A method for producing activated carbon in a heat treatment system that conveys particulate carbon feedstock to a reactor containing a burner flame comprising, introducing a buffering gas below a point of carbon feedstock injection and around the circumference of the burner flame, wherein said buffering gas is introduced tangentially around the burner flame prior to the injection of said particulate feedstock material.

2. The method of claim 1, wherein said particulate carbon feedstock is conveyed to said reactor mechanically, and said buffering gas is sufficient to impart cyclonic flow to said feedstock upon introduction to said reactor.

3. The method of claim 1, wherein said particulate carbon feedstock is conveyed pneumatically.

4. The method of claim 3, wherein said pneumatic conveyance is provided by a first gas different in composition from said buffering gas introduced around the circumference of the burner flame.

5. The method of claim 1, wherein the buffering gas is comprised of one or more of recirculated flue gases, air, moisture, CO_2, or nitrogen.

6. The method of claim 1, wherein said buffering gas creates a zone in the reactor that is substantially free of carbon feedstock.

7. The method of claim 1, further comprising injecting moisture through a center portion of the burner flame down the linear length of the reactor through one or more spray lances such that said carbon feedstock is not contacted by said moisture until said feedstock undergoes at least one revolution or travels at least one half reactor diameter within said reactor, and wherein moisture is injected into and present in the reactor before said carbon feedstock enters.

8. The method of claim 7, wherein said one or more spray lances are even with a face of said burner.

9. The method of claim 7, wherein the moisture injection comprises air atomized water or steam.

10. The method of claim 7, wherein the injected moisture also contains a chemical additive.

11. The method of claim 7, wherein the moisture injection spray pattern angle is about between 10 and 30 degrees relative to said burner face plane.

12. The method of claim 7, wherein the moisture injection spray pattern angle is about 20 degrees relative to said burner face plane.

13. The method of claim 7, further comprising injecting moisture through a center portion of the burner flame down the linear length of the reactor through one or more spray lances such that said carbon feedstock is not contacted by said moisture until said feedstock fully entrains in a cyclonic gas flow with a minimum linear conveying velocity of no less than 35 feet per second, and wherein moisture is injected into and present in the reactor before said carbon feedstock enters.

14. The method of claim 3, wherein said pneumatic conveyance and said buffering gas are independently controllable.

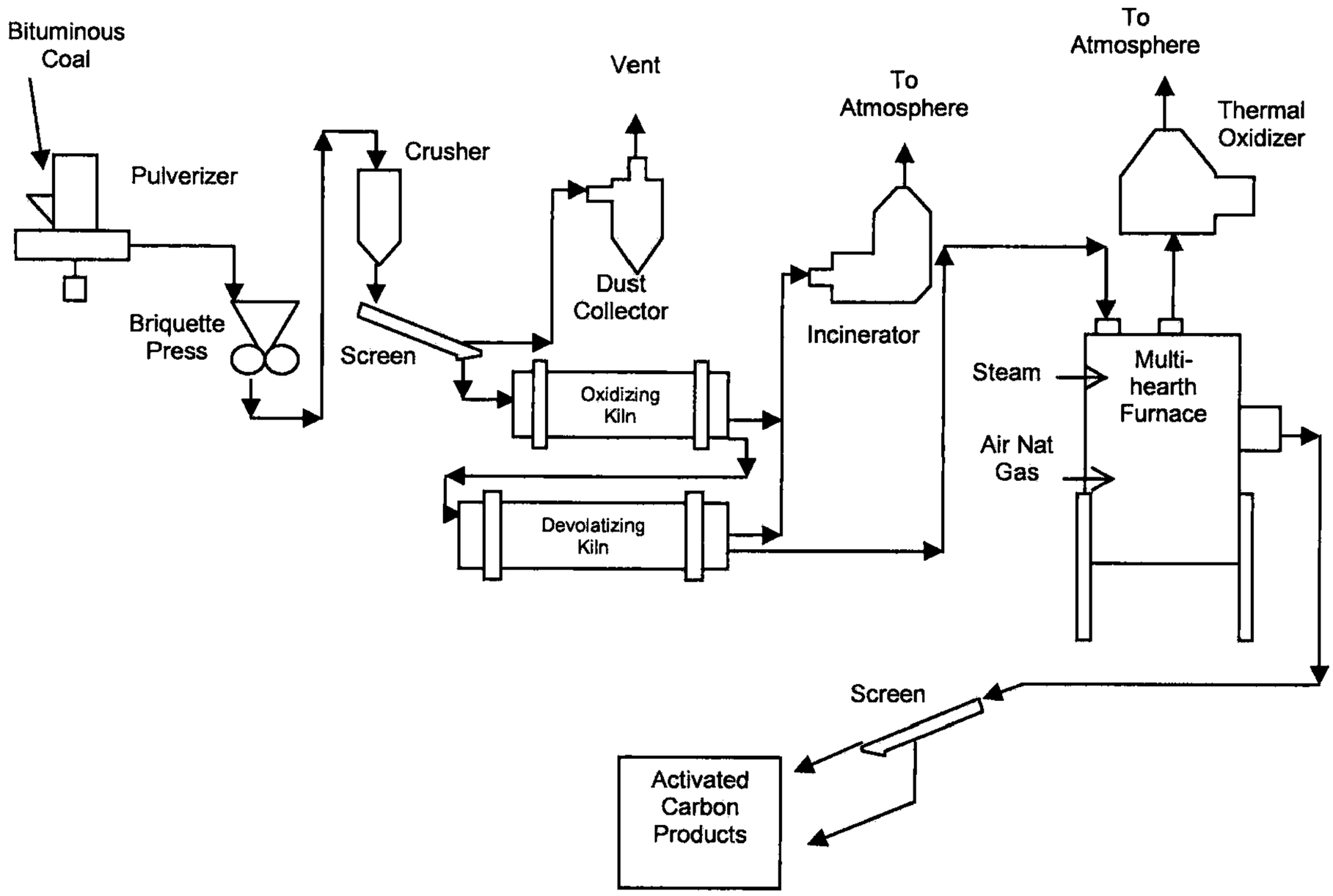


Fig. 1 (Prior Art)

Fig. 2

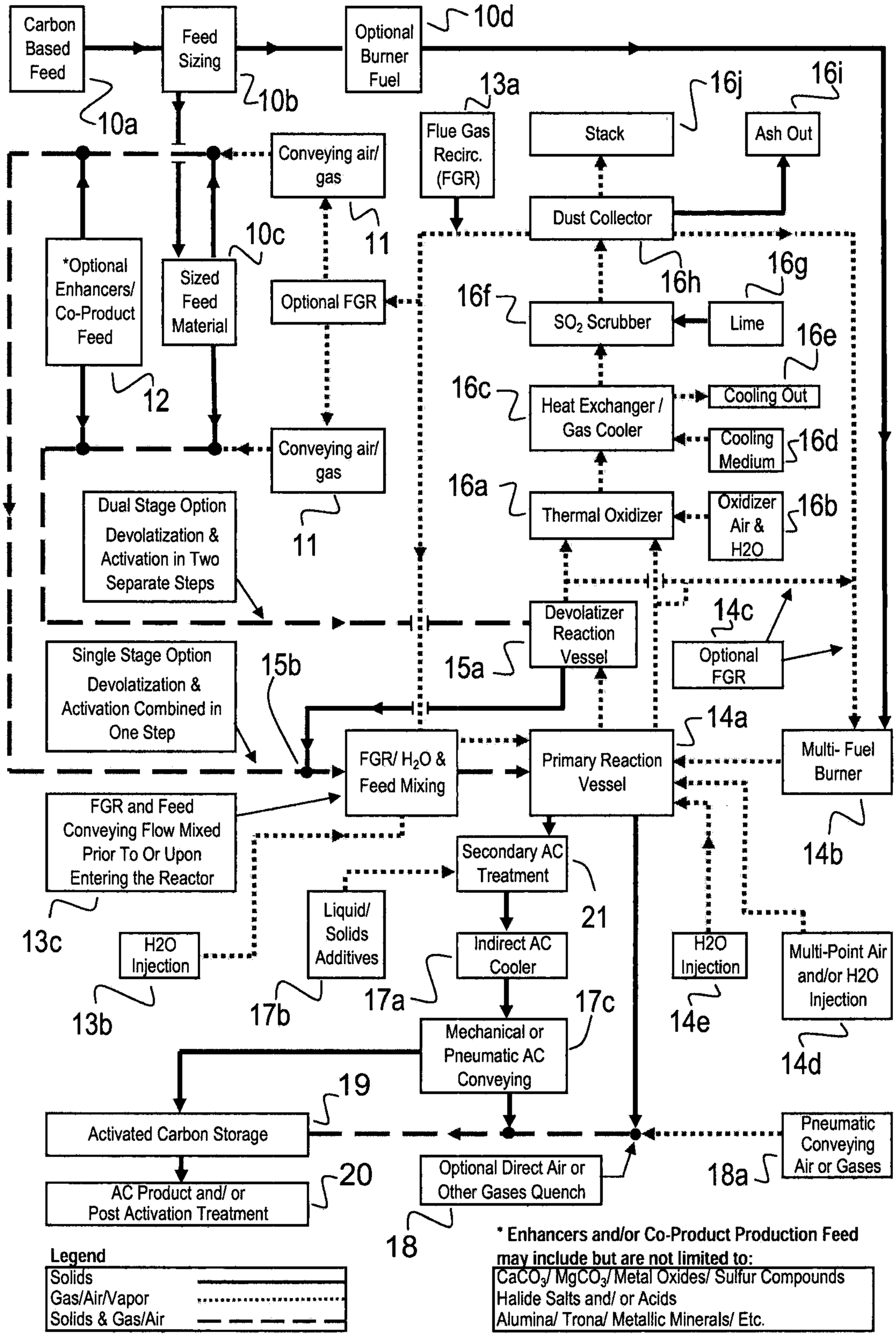

Carbon Based Feed
Feed Sizing
Optional Burner Fuel
10d
10a
10b
13a
16j
16i
Flue Gas Recirc. (FGR)
Stack
Ash Out
Conveying air/ gas
Dust Collector
10c
11
*Optional Enhancers/ Co-Product Feed
Sized Feed Material
Optional FGR
16h
16g
16f
SO_2 Scrubber
Lime
16e
12
16c
Heat Exchanger / Gas Cooler
Cooling Out
Conveying air/ gas
Cooling Medium
16d
16a
Thermal Oxidizer
Oxidizer Air & H2O
16b
11
Dual Stage Option Devolatization & Activation in Two Separate Steps
Devolatizer Reaction Vessel
14c
15a
Optional FGR
Single Stage Option Devolatization & Activation Combined in One Step
15b
14a
Multi- Fuel Burner
FGR/ H_2O & Feed Mixing
Primary Reaction Vessel
FGR and Feed Conveying Flow Mixed Prior To Or Upon Entering the Reactor
Secondary AC Treatment
21
14b
13c
Liquid/ Solids Additives
H2O Injection
Indirect AC Cooler
H2O Injection
Multi-Point Air and/or H2O Injection
13b
17b
17a
17c
14e
14d
Mechanical or Pneumatic AC Conveying
19
Activated Carbon Storage
Pneumatic Conveying Air or Gases
18a
20
AC Product and/ or Post Activation Treatment
Optional Direct Air or Other Gases Quench
18
Legend
Solids
Gas/Air/Vapor
Solids & Gas/Air
* Enhancers and/or Co-Product Production Feed may include but are not limited to:
$CaCO_3$/ $MgCO_3$/ Metal Oxides/ Sulfur Compounds
Halide Salts and/ or Acids
Alumina/ Trona/ Metallic Minerals/ Etc.

Fig. 3

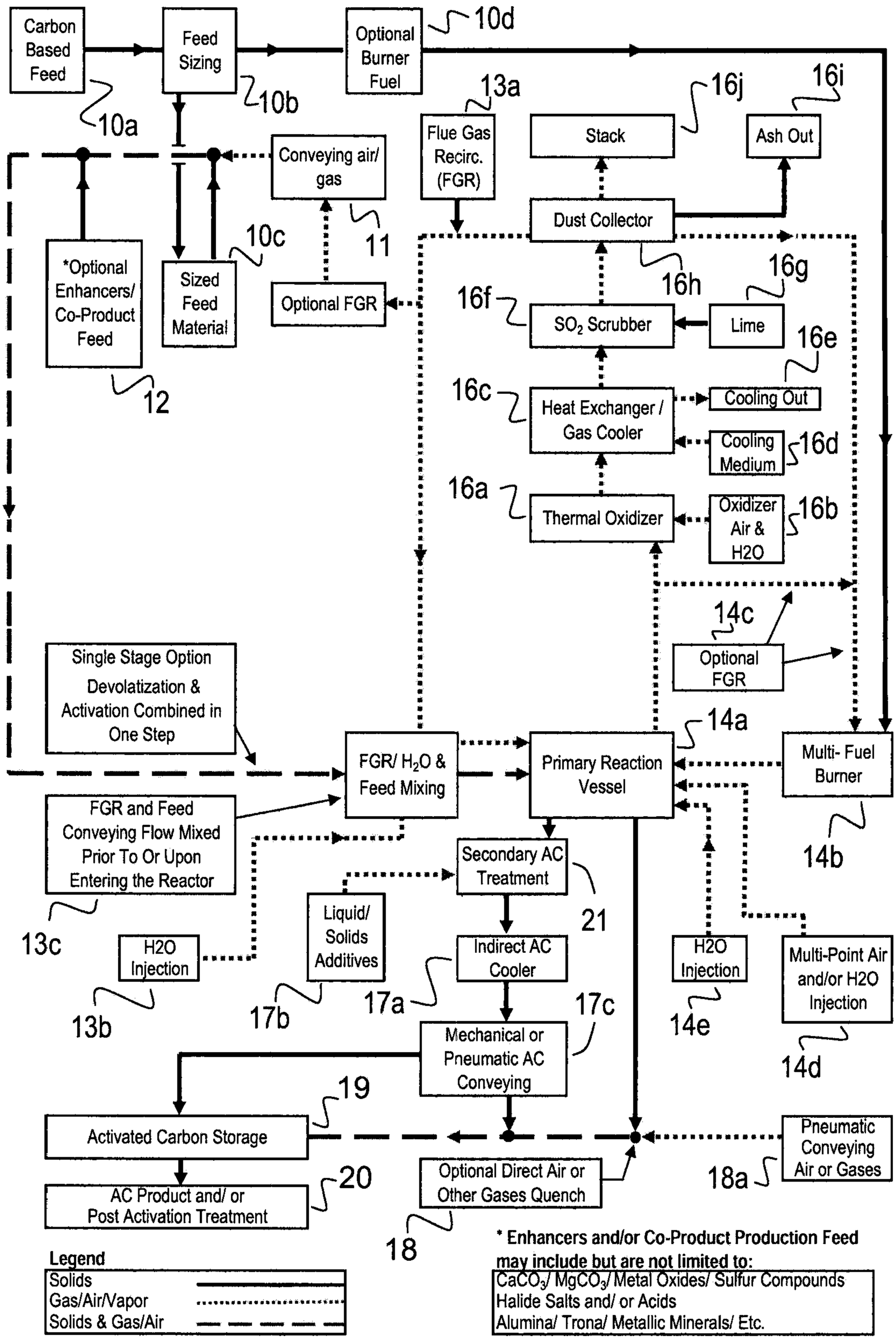
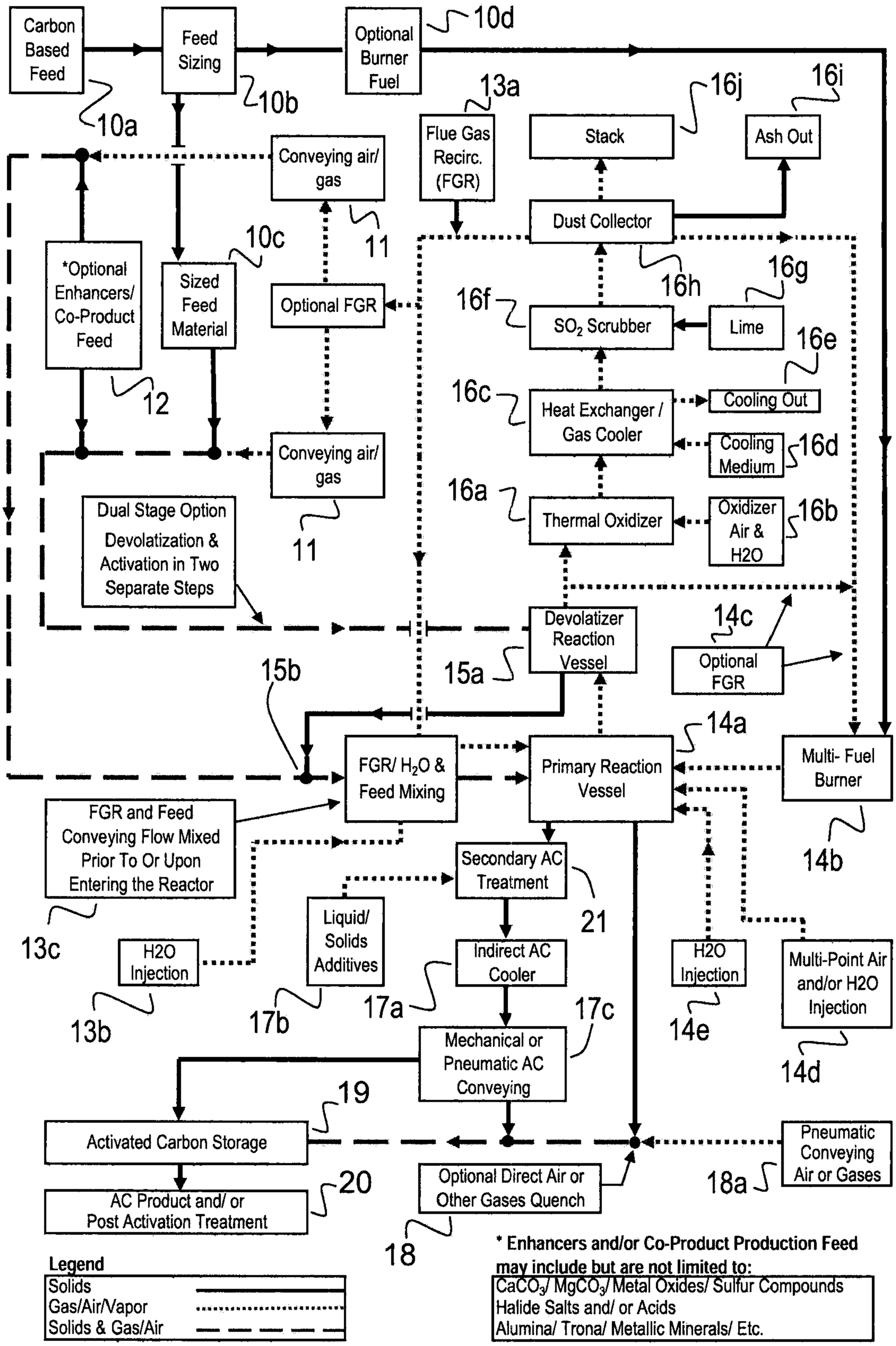

Carbon Based Feed
Feed Sizing
Optional Burner Fuel
10d
10a
10b
13a
16j
16i
Flue Gas Recirc. (FGR)
Stack
Ash Out
Conveying air/ gas
11
10c
Dust Collector
*Optional Enhancers/ Co-Product Feed
Sized Feed Material
Optional FGR
16h
16g
16f
SO_2 Scrubber
Lime
16e
12
16c
Heat Exchanger / Gas Cooler
Cooling Out
Cooling Medium
16d
16a
Thermal Oxidizer
Oxidizer Air & H2O
16b
14c
Single Stage Option Devolatization & Activation Combined in One Step
Optional FGR
14a
FGR/ H_2O & Feed Mixing
Primary Reaction Vessel
Multi- Fuel Burner
14b
FGR and Feed Conveying Flow Mixed Prior To Or Upon Entering the Reactor
Secondary AC Treatment
21
13c
Liquid/ Solids Additives
H2O Injection
Indirect AC Cooler
H2O Injection
Multi-Point Air and/or H2O Injection
13b
17b
17a
17c
14e
14d
Mechanical or Pneumatic AC Conveying
19
Activated Carbon Storage
Pneumatic Conveying Air or Gases
18a
20
AC Product and/ or Post Activation Treatment
Optional Direct Air or Other Gases Quench
18
Legend
Solids
Gas/Air/Vapor
Solids & Gas/Air
* Enhancers and/or Co-Product Production Feed may include but are not limited to:
$CaCO_3$/ $MgCO_3$/ Metal Oxides/ Sulfur Compounds
Halide Salts and/ or Acids
Alumina/ Trona/ Metallic Minerals/ Etc.

Fig. 4


Carbon Based Feed
10a
Feed Sizing
10b
Optional Burner Fuel
10d
13a
16j
16i
Flue Gas Recirc. (FGR)
Stack
Ash Out
Conveying air/ gas
11
Dust Collector
16h
16g
*Optional Enhancers/ Co-Product Feed
12
Sized Feed Material
10c
Optional FGR
16f
SO_2 Scrubber
Lime
16e
16c
Heat Exchanger / Gas Cooler
Cooling Out
Cooling Medium
16d
Conveying air/ gas
11
16a
Thermal Oxidizer
Oxidizer Air & H2O
16b
Dual Stage Option
Devolatization & Activation in Two Separate Steps
Devolatizer Reaction Vessel
15a
15b
14c
Optional FGR
14a
FGR/ H_2O & Feed Mixing
Primary Reaction Vessel
Multi- Fuel Burner
14b
FGR and Feed Conveying Flow Mixed Prior To Or Upon Entering the Reactor
13c
Secondary AC Treatment
21
Liquid/ Solids Additives
17b
H2O Injection
13b
Indirect AC Cooler
17a
H2O Injection
14e
Multi-Point Air and/or H2O Injection
14d
17c
Mechanical or Pneumatic AC Conveying
19
Activated Carbon Storage
Pneumatic Conveying Air or Gases
18a
20
AC Product and/ or Post Activation Treatment
Optional Direct Air or Other Gases Quench
18
Legend
Solids
Gas/Air/Vapor
Solids & Gas/Air
* Enhancers and/or Co-Product Production Feed may include but are not limited to:
$CaCO_3$/ $MgCO_3$/ Metal Oxides/ Sulfur Compounds
Halide Salts and/ or Acids
Alumina/ Trona/ Metallic Minerals/ Etc.

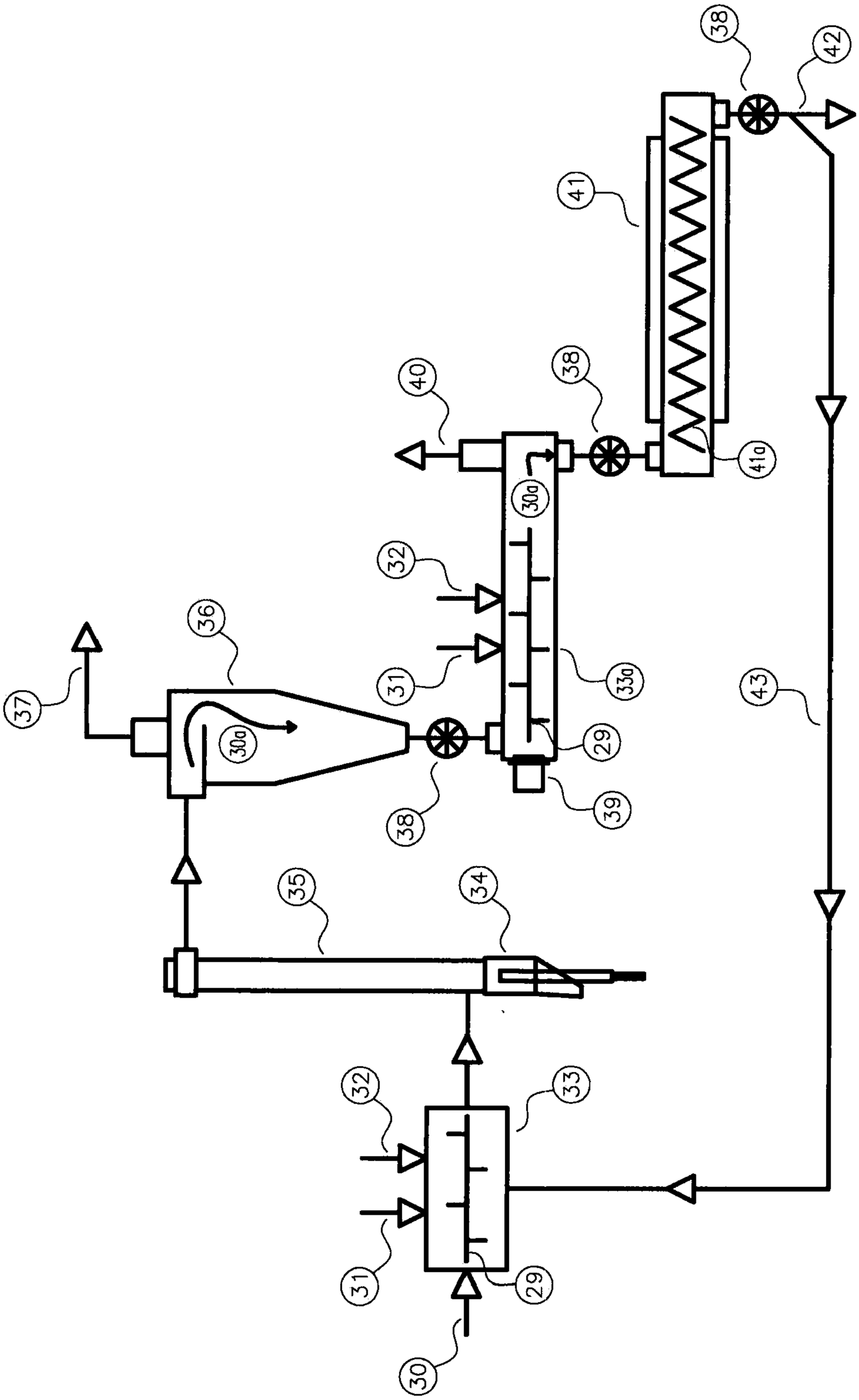

38
42
41
40
38
41a
30a
32
36
31
33a
37
30a
29
38
39
43
35
34
32
33
31
29
30

Fig. 5

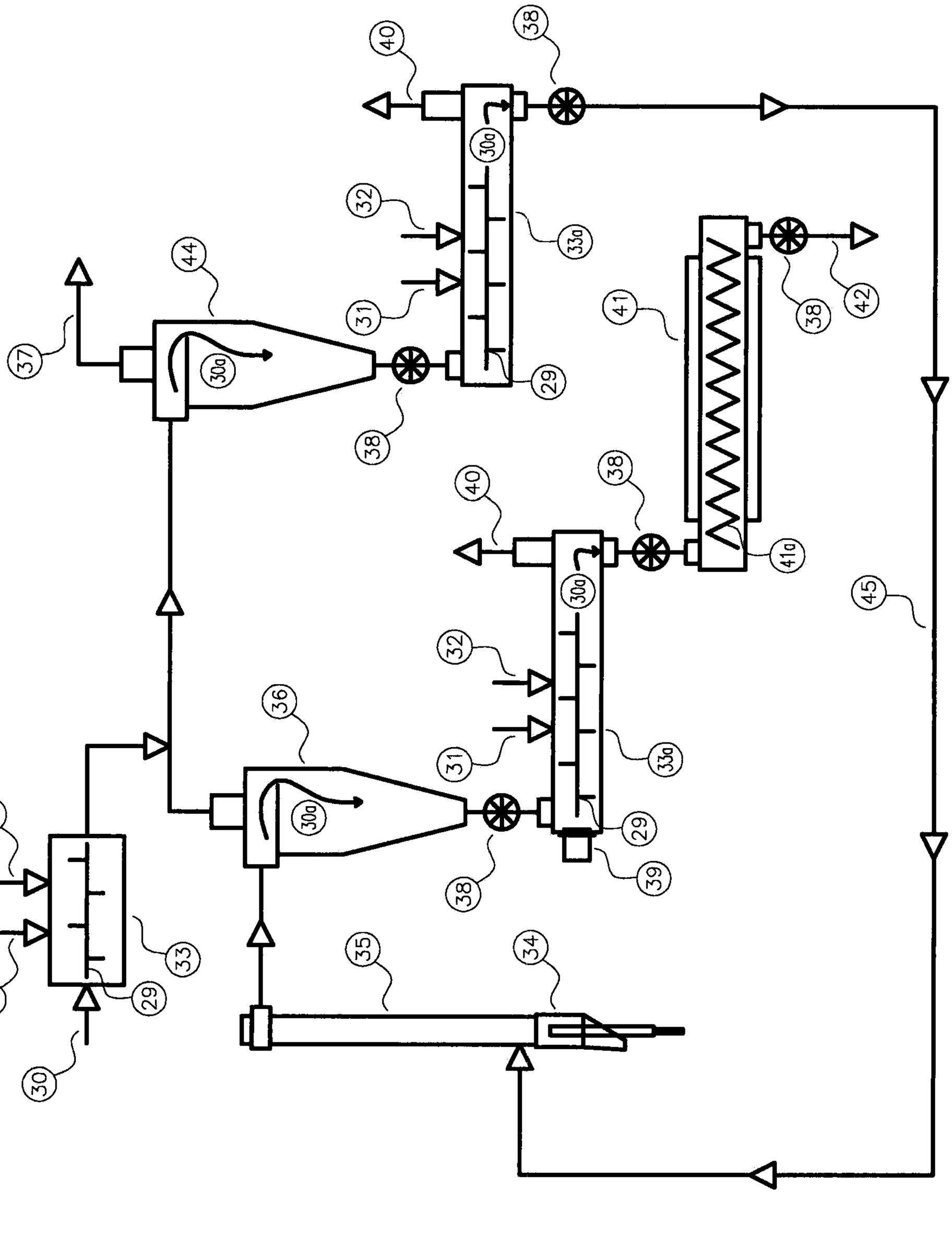

40
38
30a
32
33a
31
44
37
30a
29
38
41
38
42
41a
40
38
30a
32
36
45
31
33a
30a
29
39
38
32
33
31
29
35
34
30

Fig. 6

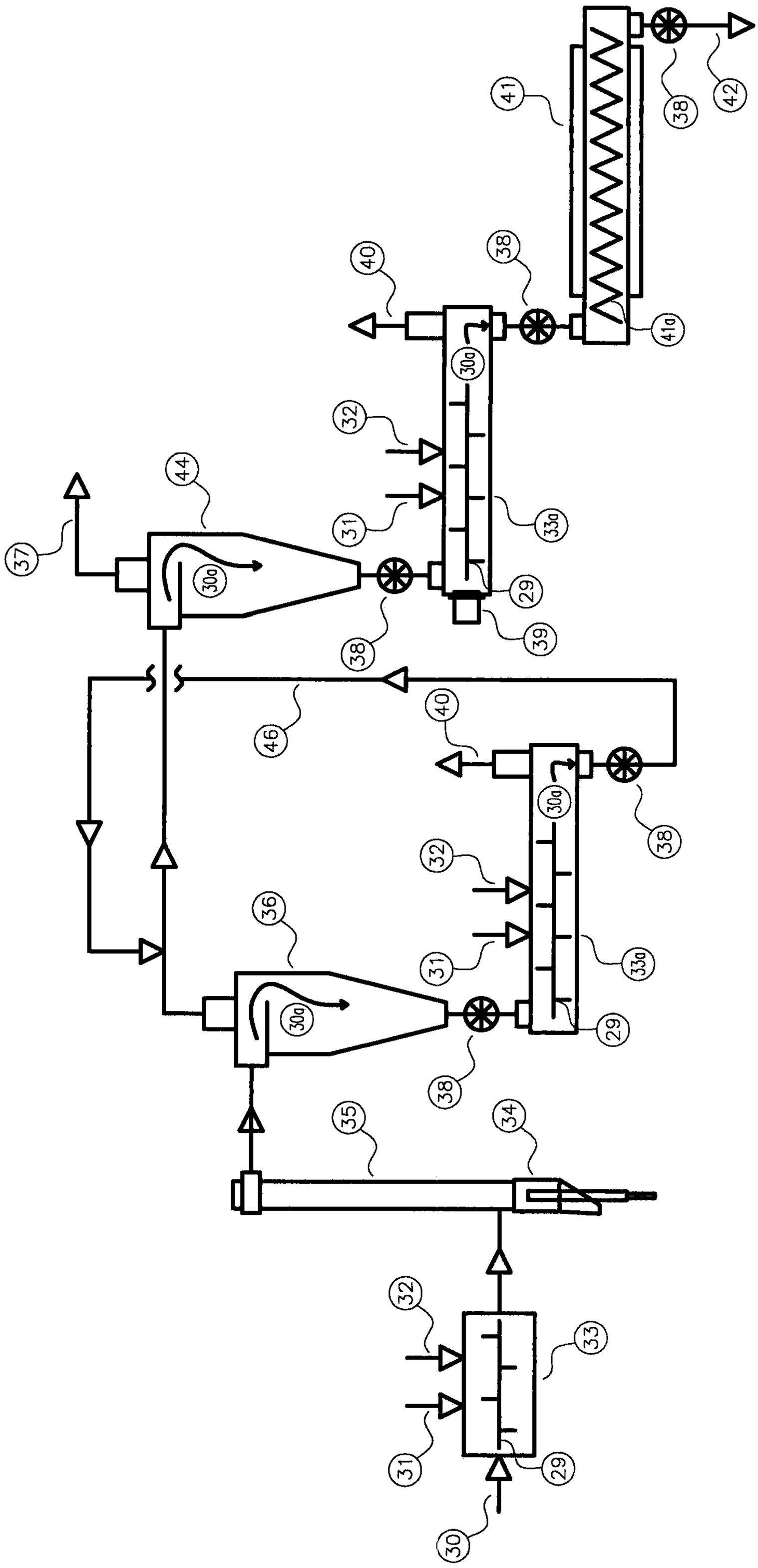

41
38
42
40
38
41a
30a
32
31
33a
29
39
44
37
30a
38
40
46
30a
32
31
33a
29
38
36
30a
35
34
32
33
31
29
30

Fig. 7

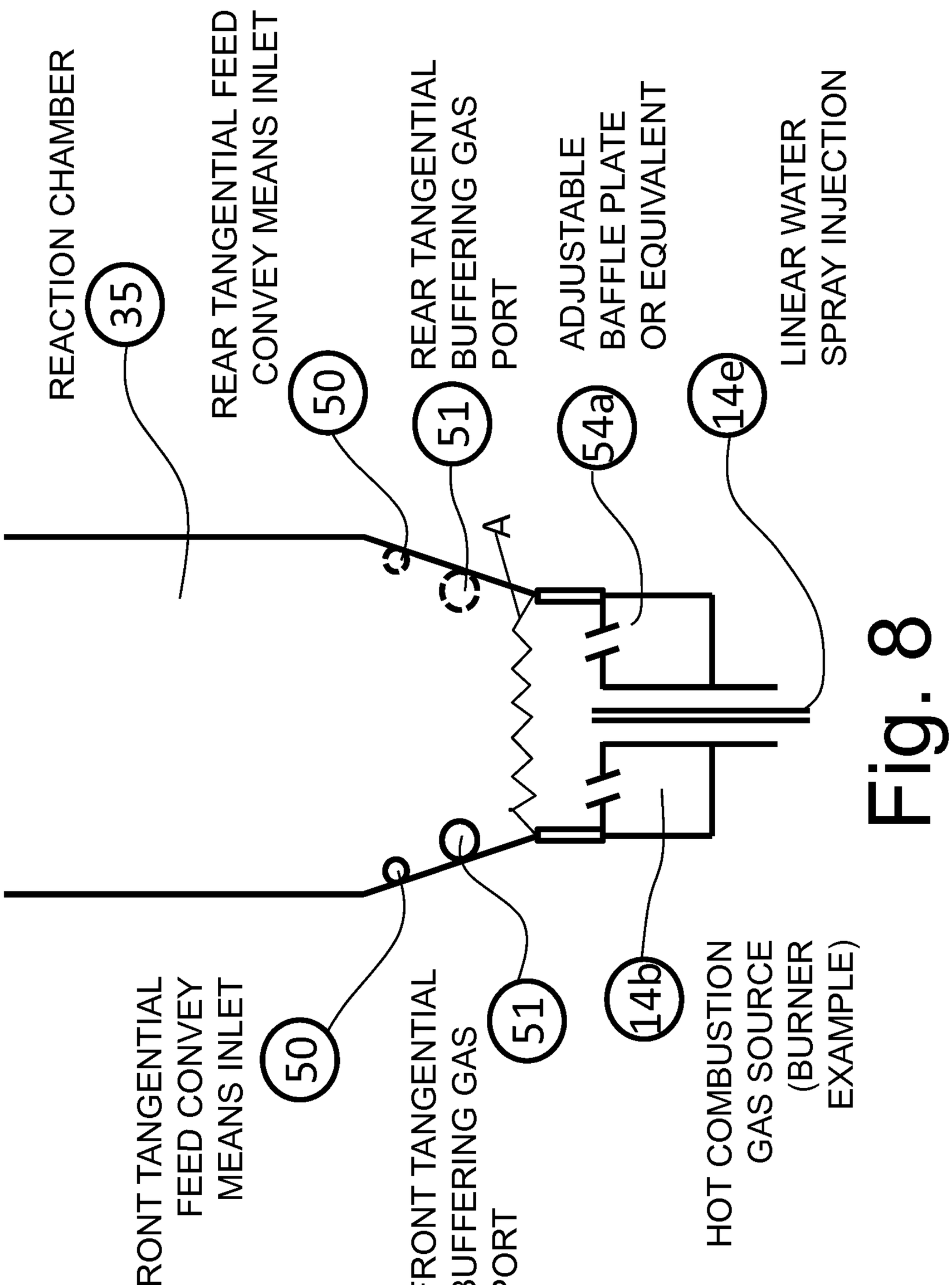

REACTION CHAMBER
35
REAR TANGENTIAL FEED
CONVEY MEANS INLET
50
REAR TANGENTIAL
BUFFERING GAS
PORT
51
A
ADJUSTABLE
BAFFLE PLATE
OR EQUIVALENT
54a
14e
LINEAR WATER
SPRAY INJECTION
FRONT TANGENTIAL
FEED CONVEY
MEANS INLET
50
FRONT TANGENTIAL
BUFFERING GAS
PORT
51
14b
HOT COMBUSTION
GAS SOURCE
(BURNER
EXAMPLE)

Fig. 8

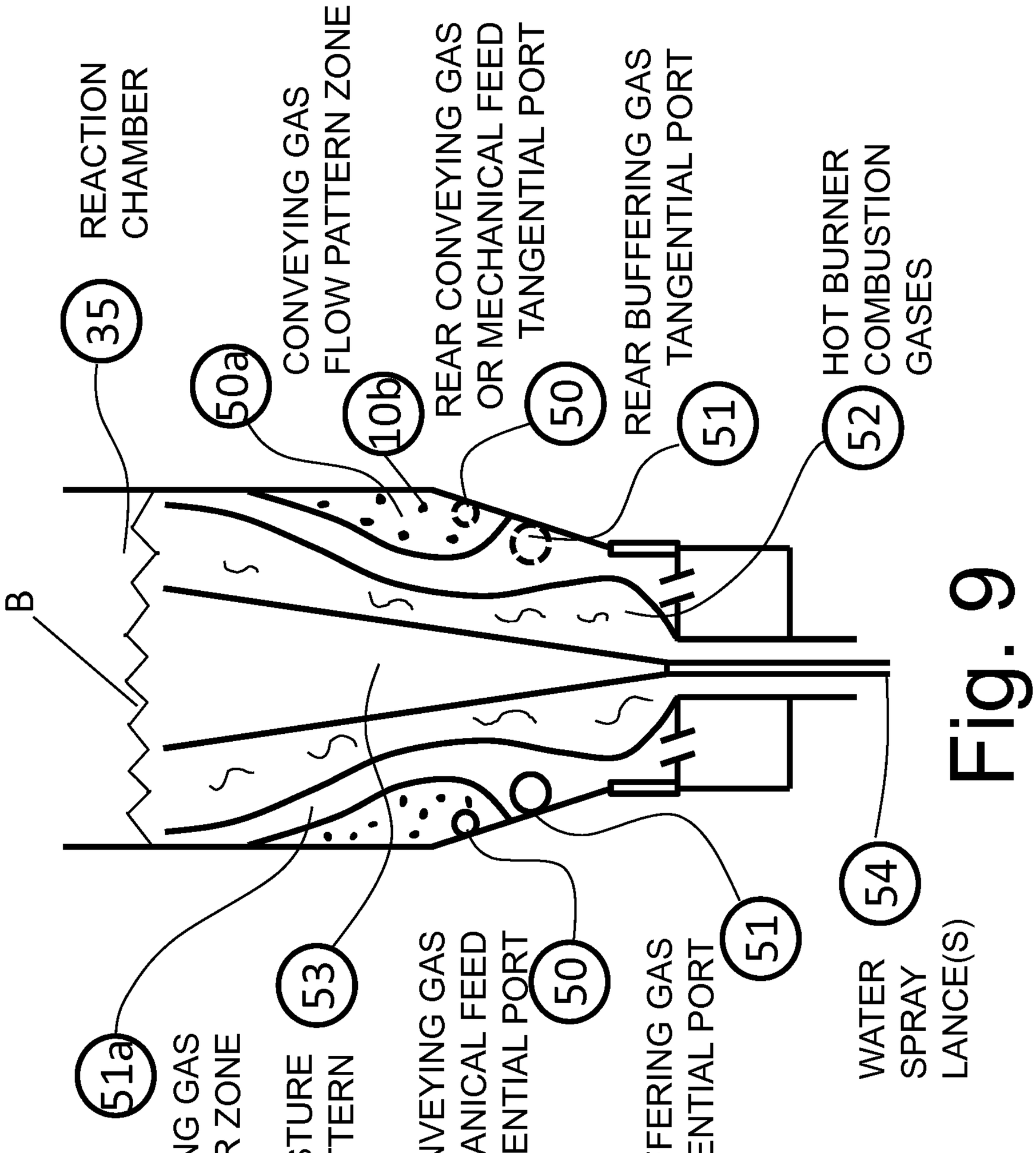

REACTION CHAMBER
35
CONVEYING GAS FLOW PATTERN ZONE
50a
REAR CONVEYING GAS OR MECHANICAL FEED TANGENTIAL PORT
10b
REAR BUFFERING GAS TANGENTIAL PORT
50
HOT BURNER COMBUSTION GASES
51
52
B
51a
BUFFERING GAS BUFFER ZONE
LINEAR MOISTURE SPRAY PATTERN
53
FRONT CONVEYING GAS OR MECHANICAL FEED TANGENTIAL PORT
50
FRONT BUFFERING GAS TANGENTIAL PORT
51
WATER SPRAY LANCE(S)
54

Fig. 9

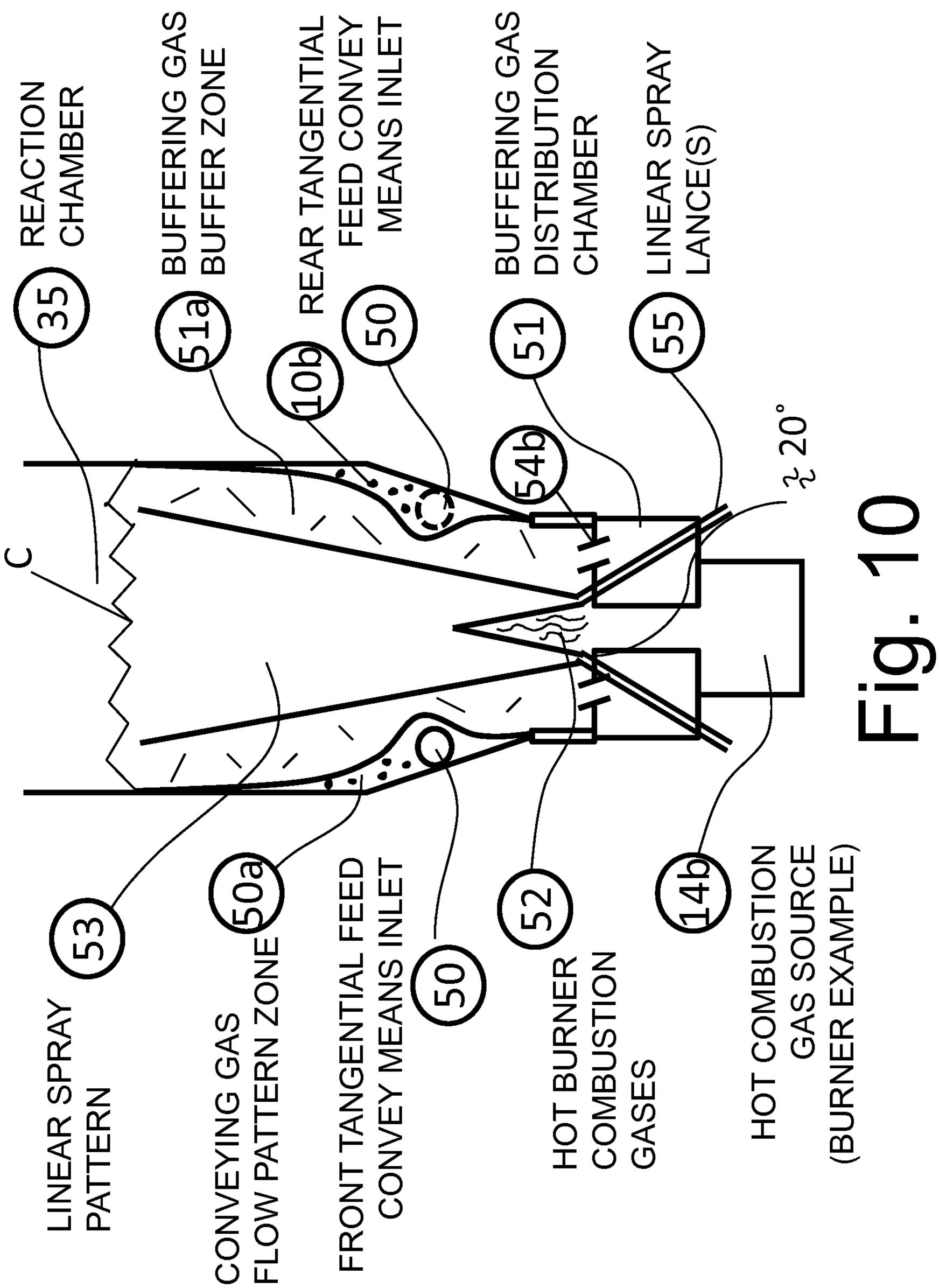

REACTION CHAMBER
35
BUFFERING GAS
BUFFER ZONE
51a
REAR TANGENTIAL FEED
FEED CONVEY MEANS INLET
10b
50
BUFFERING GAS
DISTRIBUTION CHAMBER
54b
51
LINEAR SPRAY LANCE(S)
55
≈ 20°
C
LINEAR SPRAY PATTERN
53
CONVEYING GAS FLOW PATTERN ZONE
50a
FRONT TANGENTIAL FEED CONVEY MEANS INLET
50
HOT BURNER COMBUSTION GASES
52
HOT COMBUSTION GAS SOURCE (BURNER EXAMPLE)
14b

Fig. 10

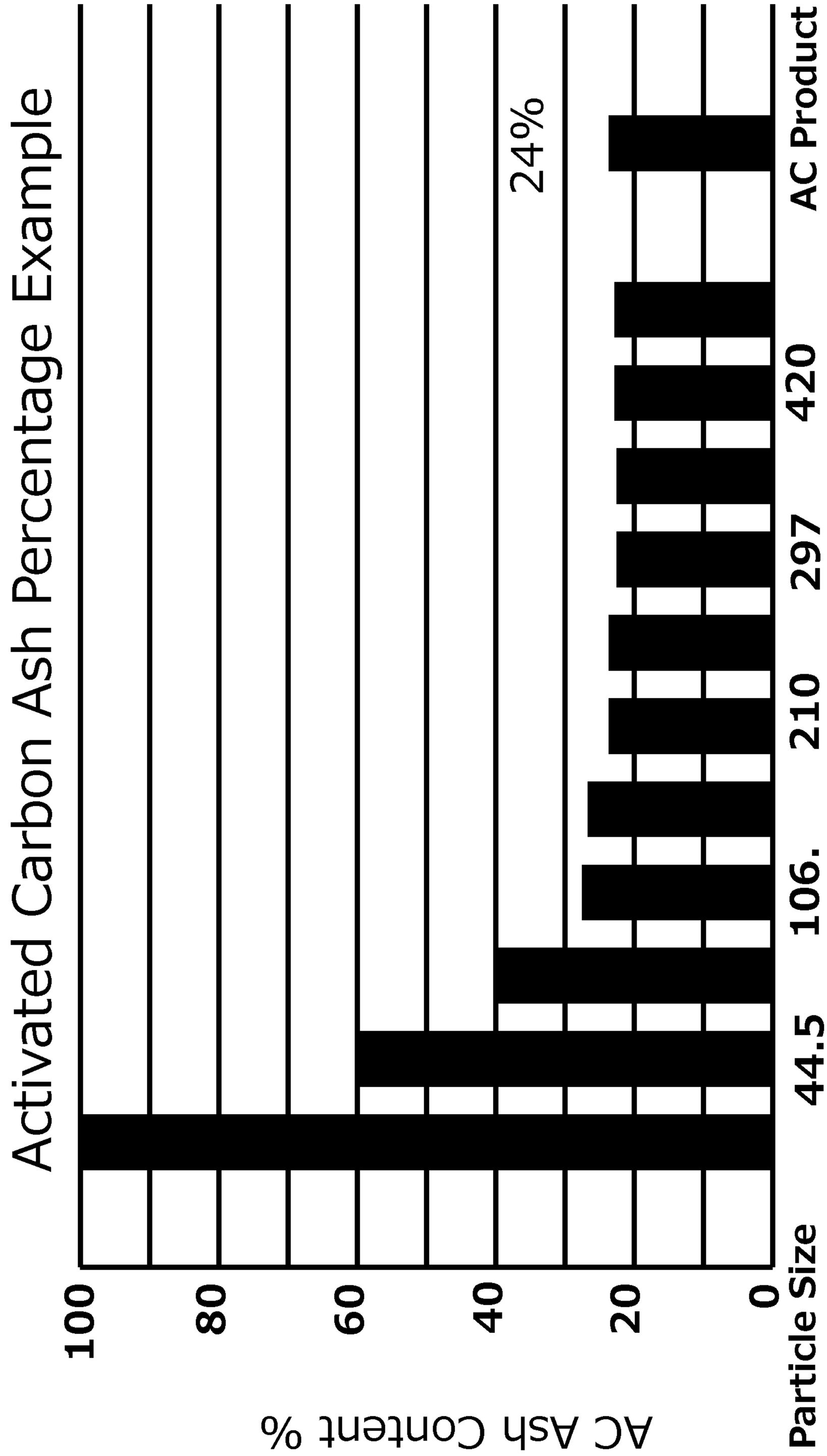
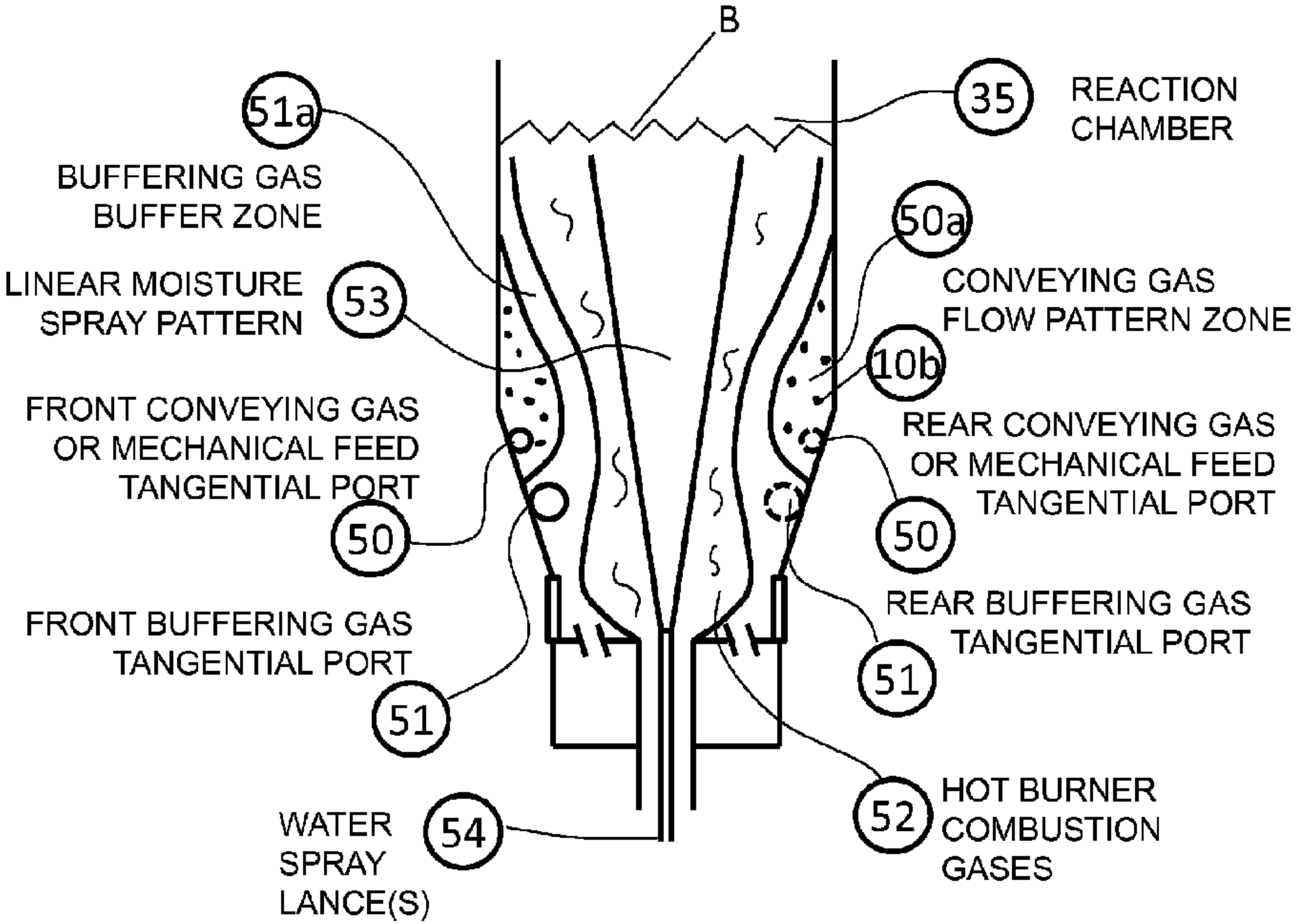

Activated Carbon Ash Percentage Example
AC Ash Content %
100
80
60
40
20
0
Particle Size (µM)
Mesh #
20.3
44.5
63.5
106.1
149
210
297
420
500
600
325
230
140
100
70
60
50
45
40
35
24%
AC Product

Fig. 11


B
51a
BUFFERING GAS
BUFFER ZONE
35
REACTION
CHAMBER
50a
CONVEYING GAS
FLOW PATTERN ZONE
LINEAR MOISTURE
SPRAY PATTERN
53
10b
FRONT CONVEYING GAS
OR MECHANICAL FEED
TANGENTIAL PORT
50
REAR CONVEYING GAS
OR MECHANICAL FEED
TANGENTIAL PORT
50
REAR BUFFERING GAS
TANGENTIAL PORT
FRONT BUFFERING GAS
TANGENTIAL PORT
51
51
WATER
SPRAY
LANCE(S)
54
52
HOT BURNER
COMBUSTION
GASES