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(54) Title: AN APPARATUS FOR PRODUCING BIOFUELS FROM BIOMASS

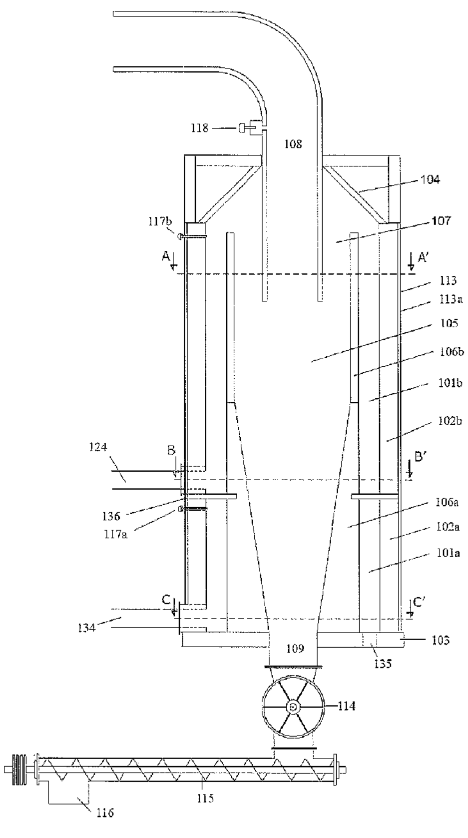

Figure 1

(57) Abstract: An apparatus for producing fuels from biomass comprises of (i) a reaction chamber defined by an integral space form by an outer inverted cyclone structure and an inner cyclone structure with an open-end lower tapered section and a tubular outlet at the top. The inner cyclone structure is enclosed coaxially within the outer cyclone structure; (ii) a combustion chamber disposed underneath the reaction chamber; in addition, infeed inlets are mounted tangentially onto the sidewalls of the outer cyclone structure and the combustion chamber for infeed of biomass with high speed blown gas. The combustion chamber generates and supplies heat to the reaction chamber by combustion of biomass up to temperatures 800°C. Biomass feedstock is injected into the reaction chamber to form a vortex swirling at high speed wherein the biomass is converted into torrefied product, fuel vapor or producer gas under different operation conditions under the control of a PLC. The gaseous products exit through the tubular outlet at the top while the solid products or solid remnants such as ash are discharged through the bottom opening of the inner cyclone structure to a water-cooled discharging screw conveyor assembly.

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AN APPARATUS FOR PRODUCING BIOFUELS FROM BIOMASS

FIELD OF INVENTION

The invention relates to an apparatus for producing fuels from biomass. In more particular, the invention relates to an apparatus for producing fuels from biomass, in which enhanced thermal conversion process is achieved by rapid and vigorous mixing resulted from a cyclonic motion of a vortex generated therein.

BACKGROUND OF THE INVENTION

Fossil fuels have always been a dominant source for global energy consumption which increases at a substantial rate with growth of population and industrialization. Today, depletion of fossil energy resources and generation of greenhouse gases due to excessive consumption of fossil fuels have caught global attention to seek for alternative energy resources which are sustainable and environmentally friendly.

Biomass arises as a promising energy resource to supplement fossil fuels, due to its abundant amount. Generally, biomass refers to carbon based organic materials produced by photosynthesis. The carbonaceous compounds contained in the biomass can be converted thermally to generate energy. Examples of biomass include but are not limited to terrestrial vegetation, residues from forestry or agriculture, animal wastes and municipal wastes. Biomass consists of three types of polymeric components which are cellulose, hemicellulose and lignin. It can be converted by a thermal conversion process either in absence of oxygen or in oxygen-limiting condition to different forms of fuels, such as bio-char, bio-oil or combustible gas also known as producer gas.

Different forms of fuels and their relative proportion produced depends on methods of conversion process, characteristics of feedstock and reaction parameters, such as heating rate, temperature and pressure, oxygen content of the heating atmosphere and residence time of biomass in the conversion reactor.

Under the action of heat, biomass undergoes three thermal conversion processes, namely, pyrolysis, combustion and gassification. Pyrolysis of biomass is a thermal decomposition process in the absence of oxygen. The pyrolysis process takes place as follows:

(a) at temperatures up to 200°C, water and volatile products such as acetic and formic acid are released;

(b) at temperatures between 200 and 300°C, biomass undergoes a partial pyrolysis process known as torrefaction, in which lignocellulose structure is depolymerised and devotalised along with release of pyroligneous acids, water, and non-condensable gases (carbon monoxide (CO), carbon dioxide (CO_2));

(c) at temperatures between 300 to 650°C, actual pyrolysis takes place, producing mainly biochar, tar and non-condensable gases containing mainly carbon dioxide (CO_2); and

(d) at temperatures between 450 and 650°C, the volatile matters are released as liquid vapour, char and non-condensable gaseous products containing hydrogen.

Typically, hemicellulose, the most reactive component, is almost completely devolatilised and depolymerized at temperatures ranging from 200 to 300°, whilst cellulose and lignin are depolymerised and devolatilised at 300 to 400°C and 250 to 500°C respectively.

Pyrolysis can be categorized into slow and fast pyrolysis. Slow pyrolysis takes several hours to complete and results in biochar as the main product. In the fast pyrolysis process, on the other hand, the biomass is heated up to above 450°C within fractions of a second to skip over liquid tar formation and decompose the volatile matters to liquid vapour which is condensable to a viscous black liquor known as bio-oil. The fast pyrolysis process is also often characterized by high heating rates, short residence time and rapid quenching to obtain high yield of liquid products.

Pyrolysis is followed by the combustion process where volatile products and some char react with oxygen to produce carbon monoxide and carbon dioxide, generating heat required for the subsequent reactions. At temperatures between 650 to 1200°C, the liquid fuel vapour is converted to combustible gases through a redox process or a combined oxidation-reduction process under sub-stoichiometric conditions known as gasification in which char reacts with carbon dioxide and steam to produce carbon monoxide, hydrogen and trace of methane. The reactions occur at temperatures above 650°C.

Torrefaction of biomass is a process in which the biomass is heated at a temperature ranging from 200 to 350°C in oxygen-limiting condition. During the torrefaction, the biomass can either be heated directly using a gaseous heating medium such as inert gases, superheated steam, or be heated indirectly through contact with a hot surface. The heating results in devolatilisation and depolymerisation of major components of the biomass (hemicellulose, cellulose and lignin) and weight loss in biomass due to emission of moisture, volatile hydrocarbon and some gases. Resultant torrefied biomass or bio-char, which is a dry, brittle and darkened material, has an enhanced energy value measured in terms of heat energy per unit of weight.

Gaseous or liquid fuels can be produced by fast pyrolysis of biomass. During the fast pyrolysis process, biomass is heated rapidly to temperatures between 450 to 650°C in absence of oxygen to convert its volatile matters into vapour which can be condensed to form liquid bio-oil. Various types of reactors have been developed for such objective and known as Bubbling-Fluidized Bed Reactor, Circulating-Fluidized Bed Reactor, Rotating Cone Reactor, Auger Reactor and Ablative Reactor. These reactors are designed based on different principles and some may also require external transport of hot sand as heating medium and mechanical means to remove solid residues.

In another aspect, gasification of biomass is a thermochemical process which converts volatile matters of biomass materials into combustible gas known as producer gas at temperature above 650°C under sub-stoichiometric condition. The producer gas contains mainly nitrogen, carbon dioxide, oxygen, carbon monoxide, hydrogen and trace of methane. For a commercial scale process, various types of apparatus have been developed and can be classified into fixed bed gasifier, fluidized bed gasifier and cyclonic gasifier. Nevertheless, there are certain disadvantages in these gasifiers, despite the fact that they are widely applied in the industries. The fixed bed gasifier is restricted in capacity by its slow conversion rate, bulky volume and up-scaling limit for uniform temperature distribution. Moreover, excessive heat near the reactor grate may lead to ash fusion causing agglomeration on the bed. Consistent control of temperature uniformity and air/fuel ratio is unfeasible due to the complex and inhomogeneous reactions of gasifying process and massive sizes of feedstock in the fixed bed gasifier.

The fluidized bed gasifier requires more stringent control of the particulate size of feedstock (<3 mm) in order to ensure proper bubbling on the fluidized bed. Besides, the producer gas has higher ash content and there is also a danger of bed agglomeration due to fusing of ash.

The disadvantages of a single cyclone gasifier is its relatively short residence time of solid fuel in the cyclone compared with that of fixed bed and fluidized bed gasifiers. As a result, it allows only fine particles, normally less than 3 mm, for complete conversion of solid fuels to combustible gas and the tar and char content is substantially high.

Based on the thermal conversion process and its method of heating, these reactors are designed only for a specific application, either as a torrefier, pyrolysis reactor or a gasifier. For example, a biomass gasifying device is disclosed in China Patent Publication No. 201010626. It claims a cylindrical biomass gasifying device having an upper and a lower chamber separated by a conical funnel. A funnel-shaped helical gas distribution furnace bridge is hung on the funnel opening of a conical funnel on the upper chamber, whereas an inner furnace cylinder with a material guide hole and a conical cover with a gas guide hole is provided at the bottom of the concentrical cover base of the air distribution furnace bridge. It is also disclosed that a gasifying agent inlet port is provided in the cavity of the lower chamber, while a water sealed scum pipe is provided at the bottom of the lower chamber.

Another invention related to a cyclonic gasifier is also being claimed in China Patent Publication No. 101255341. The apparatus includes a cylindrical shaped upper portion and a tapered shaped lower portion. The cylindrical shaped upper portion is an integrated combustion and gasification chamber and the tapered shaped lower portion serves as a gasification chamber. A splash board is set at the upper portion of the cylindrical shaped gasification chamber and smoke outlet is mounted on the top. A fuel inlet is mounted tangentially onto the cylindrical shaped upper portion. A resistant wire igniter is located in fuel inlet, whereas a steam inlet is disposed in center portion of the tapered shaped gasification chamber. An ash outlet is disposed at bottom.

However, none of the patented designs and technologies relates to a compact apparatus capable of performing thermal conversion processes (torrefaction, pyrolysis and gasification) under different operating conditions to produce fuels from biomass. The compact apparatus is, preferably, consisting of a reaction chamber defined by an integral space formed from a double cyclone structures (i.e. an outer and an inner cyclone structures) and a combustion chamber located underneath the reaction chamber. The thermal conversion process taking place in the apparatus can be enhanced as result of rapid and vigorous mixing resulted from a cyclonic motion of a vortex generated therein. The walls of the apparatus can also be easily heated up to a predetermined temperature by heat generated from combustion of biomass in the combustion chamber and which passes through rectangular perforations fabricated in an annular base plate disposed at bottom of the outer cyclone structure of the reaction chamber.

The invention aims to provide an apparatus capable of performing thermal or thermochemical conversion processes for torrefaction, fast pyrolysis and gasification under different operating conditions. It is desirable that the apparatus is simple in structure with no moving parts to minimize maintenance cost. It is also desirable that the apparatus is integrated with a programmable logic controller (PLC) system for easy operation and effectively controlling temperature, pressure and air/fuel ratio to maintain a stable and consistent operating condition during the thermal conversion process.

SUMMARY OF THE INVENTION

One of the aspects of the invention is to develop an apparatus capable of performing thermal or thermochemical conversion processes, including but not limited to torrefaction, pyrolysis and gasification under different operating conditions and scaling up for commercial production.

Another aspect of the invention is to provide an apparatus which enables effective control of temperature, pressure and air/fuel ratio to maintain a stable and consistent operating condition by a programmable logic controller system.

A further aspect of the invention is to develop an apparatus that enhances the heat transfer rate to the feedstock by vigorous abrasion against the heated walls of the apparatus under the action of the centrifugal force generated by the cyclonic motion of vortex generated inside the apparatus.

Still another aspect of the invention is to provide an apparatus which is simple in structure with no moving parts to minimize subsequent maintenance cost.

Yet another aspect of the present invention is to provide an apparatus that provides longer residence time to allow relatively coarser particle sizes of biomass feedstock (up to ~25 mm) for torrefaction, pyrolysis and gasification processes.

At least one of the preceding aspects is met, in whole or in part, the embodiment of the present invention describes an apparatus for producing fuels from biomass comprising:

(a) a reaction chamber defined by the integral space formed from an outer inverted cyclone structure having a cylindrical sidewall, an annular base plate fabricated with a radial array of rectangular perforations and a substantially tapered top and an inner cyclone structure having a cylindrical sidewall, an open top and a substantially tapered bottom section with an end exit opening; the outer and inner cyclone structures are arranged in such a way that the inner cyclone structure is enclosed coaxially within the outer inverted cyclone structure and the tapered bottom section of the inner cyclone structure extends downwards through the annular base plate; a tubular outlet extending from the tapered top into the upper portion of the inner cyclone structure; a feed inlet is mounted tangentially onto the sidewall of the outer cyclone structure above to the annular plate for infeed of biomass feedstock by high speed blown gas; wherein the biomass feedstock is heated up to a preset temperature rapidly on contacting the hot walls to set off thermal conversion process to produce fuel products. The mixture of air/gas, products and unconverted biomass forms a vortex and swirls upwards inside the outer cyclone structure and then downwards into the inner cyclone structure through the open top upon reaching the tapered top of the outer cyclone structure. On swirling through the reactor chamber, the biomass feedstock is kept in constant collision and abrasion with the hot walls under the action of centrifugal force generated by the cyclonic motion of vortex and heated up to the selected temperatures to set off thermal or thermochemical conversion process to produce biofuels in solid, liquid vapor and gaseous forms. The solid product or remnants such as ash or char are collected and discharge through the opening at the bottom of inner cyclone structure into the waste collection system and the gaseous products swirl upwards from the tapered bottom of the inner cyclone structure and finally exit through the outlet pipe at the top; and

(b) a combustion chamber which is defined by the sidewalls of an inner and an outside cylindrical structures, a bottom supporting base and is disposed underneath the reaction chamber to surround the sidewall of the extended tapered bottom section of the inner cyclonic structure; a feed inlet is mounted tangentially onto the sidewall of the outer cylindrical structure for infeed of biomass feedstock by high speed blown gas into the combustion chamber; wherein the biomass feedstock is combusted to generate and supply heat to the reaction chamber through the perforations in the annular plate required for the thermal or thermochemical conversion processes. The combustion chamber is maintained at a temperature not exceeding 800°C to substantially prevent fusion of the ash formed during combustion from damaging the internal walls of the combustion chamber.

In an embodiment of the invention, the apparatus is integrated with a programmable logic controller (PLC) system for automated operation and effective control of operating parameters, viz., temperature, pressure and air/fuel ratio to maintain a stable and consistent operating condition during the thermal conversion process. The air/fuel ratio in the present invention refers to ratio of biomass feedstock to air, in which the air may be a combination of fresh air and composition of the gas recovered from the condenser.

In another embodiment of the invention, the apparatus further comprises a waste collection assembly consisting of a rotary valve feeder and a water-cooled screw conveyor connected to the opening at the bottom of the inner cyclone structure for removal of the discharged solid product or remnants.

The apparatus, according to the preferred embodiments, further comprises a heat insulating layer enclosing the outer cyclone structure. The heat insulating layer is preferably a layer of mineral wool to minimize heat loss and maintain the temperature within the apparatus. The heat insulating layer is enclosed by a cylindrical hollow metal casing which serves as a protection shell for the apparatus. Preferably, the cylindrical hollow metal casing is made of mild steel.

In yet another embodiment of the invention, the apparatus further comprises:

(a) a first feeding system for the reaction chamber having a biomass feedstock storage hopper mounted with a rotary valve feeder at its bottom; an ejector is installed underneath the rotary valve feeder to inject biomass feedstock into the reaction chamber through the air/gas pipe connected to the feed inlet; a high pressure blower draws fresh air and flue gas from the exhaust outlet of the apparatus to inject through the feed inlet into the reaction chamber to serve as feedstock carrier medium. The flow rates of air and flue gas are regulated by electromagnetic actuator valves and measured by flow sensors;

(b) a second feeding system for the reaction chamber having a biomass feedstock storage hopper mounted with a rotary valve feeder at its bottom; an ejector is installed underneath the rotary valve feeder to inject biomass feedstock into the combustion chamber through the air/gas pipe connected to the feed inlet; a high pressure blower draws fresh air and flue gas from the exhaust outlet of the apparatus to inject into the combustion chamber through the feed inlet. The flow rates of air and flue gas are regulated by electromagnetic actuator valves and measured by flow sensors;

(c) a high efficiency cyclone dust collector to receive the gaseous products from the outlet of the apparatus for removal of the suspended solid remnants such as ash and char; and

(d) a cooler/condenser disposed after the cyclone dust collector to reduce the temperature of the non-condensable gases or to condense the fuel vapour to liquid bio-oil.

One skilled in the art will readily appreciate that the invention is well adapted to carry out the aspects and obtain the ends and advantages mentioned, as well as those inherent therein. The embodiments described herein are not intended as limitations on the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For the purpose of facilitating a clearer understanding of the invention, the following descriptions of the invention of the apparatus, its construction and operation and its advantages is illustrated with the figures below.

Figure 1 shows a front elevational view of the apparatus, according to the preferred embodiment of the present invention.

Figure 2 shows the isomeric view of an annular plate having a radial array of rectangular perforations, according to the preferred embodiment of the invention.

Figure 3 shows a top sectional view of the apparatus along the dashed cutting plane line A-A'.

Figure 4 shows a sectional view of the apparatus along the dashed cutting plane line B-B'.

Figure 5 shows a sectional view of the apparatus along the dashed cutting plane line C-C'.

Figure 6 shows a schematic diagram illustrating operation of the apparatus and the ancillary equipment, according to the preferred embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, the invention shall be described according to the preferred embodiments of the present invention and by referring to the accompanying description and drawings. However, it is to be understood that limiting the description to the preferred embodiments of the invention and to the drawings is merely to facilitate discussion of the present invention and it is envisioned that those skilled in the art may devise various modifications without departing from the scope of the appended claim.

This invention relates to an apparatus for producing fuels from biomass. In more particular, the invention relates to an apparatus for producing fuels from biomass, in which enhanced thermal or thermochemical conversion process is achieved by rapid and vigorous mixing resulted from the action of centrifugal force generated by the cyclonic motion of vortex generated therein.

With reference to Figure 1, this invention discloses an apparatus for producing fuels from biomass comprising:

(a) a reaction chamber (101b, 105) defined by an integral space formed from an outer inverted cyclone structure (101b), defined by a cylindrical sidewall (102b), an annular base plate (136) fabricated with a radial array of rectangular perforations and a substantially tapered top (104), and an inner cyclone structure (105), having a cylindrical sidewall (106b), an top opening (107) and a substantially tapered bottom section (106a) with an end exit opening (109); wherein the outer and inner cyclone structures are arranged in such a way that the inner cyclone structure is enclosed coaxially within the outer cyclone structure and the tapered bottom (106a) of the inner cyclone structure extends downwards through the annular base plate (136); a tubular outlet (108) extending from the tapered top (104) into the top opening of the inner cyclone structure (107); a first feed inlet (124) mounted tangentially to the sidewall of the outer cyclone structure (102b) above to the annular plate (136) for infeed of biomass feedstock by high speed blown gas delivered by a high pressure blower (125); a heating means such as oil burner or gas burner can be installed to the feed inlets (124) for pre-heating of the chambers before thermal conversion process starts; and

(b) a combustion chamber (101a) having a cylindrical structure which is defined by the sidewalls of an inner cylindrical structure (106a), an outer cylindrical structure (102a) and a bottom supporting base (103) and disposed underneath the reaction chamber (101b) to surround the extended tapered bottom section (106a) of the inner cyclone structure; a second feed inlet (134) mounted tangentially to the sidewall of the outer cylindrical structure (102a) above to the supporting base (103) for infeed of biomass feedstock by high speed blown gas delivered by a high pressure blower

(137); wherein biomass is combusted to generate and supply heat to the reaction chamber (101b, 105) through the perforations in the annular base plate (136) required for thermal or thermochemical conversion processes in the reaction chamber; The combustion chamber is maintained at a temperature not exceeding 800°C to substantially prevent fusion of the ash formed during combustion from damaging the internal walls of the combustion chamber.

In an embodiment of the invention, the apparatus further consists of a waste collection assembly, comprising of a rotary valve feeder (114) installed beneath the second opening (109) of the cyclone reactor (105) and a water-cooled discharging screw conveyor (115) connected to the outlet of rotary valve (114). The solid remnants, such as ash and char discharged through the rotary valve feeder (114), are cooled and transferred to the waste chamber (116) via a water-cooled discharging screw conveyor (115). The solid remnants in the combustion chamber (101a) can be discharged through the exit (135) at the base to avoid accumulation of unwanted solid remnants.

The apparatus, according to the preferred embodiments, further comprises a heat insulating layer (113a) enclosing the sidewalls of the outer cyclone structure (102a, 102b). The heat insulating layer is preferably a layer of mineral wool to minimize heat loss and maintain the temperature within the apparatus. The heat insulating layer is further enclosed by a cylindrical hollow metal casing (113) which serves as a protection shell for the apparatus. Preferably, the cylindrical hollow metal casing is made of mild steel.

In order to enable the apparatus to operate up to temperature of 1000°C, the walls (102, 106b) of the combustion and reactions chambers are built with refractory material or high temperature alloys which are able to retain its strength at temperatures as high as 1200°C.

In another embodiment of the invention, the apparatus, with reference to Figure 6, further comprises:

(a) a first feeding system for the reaction chamber having a biomass feedstock storage hopper (110) mounted with a rotary valve feeder (111) at its bottom; an ejector (123) is installed underneath the rotary valve feeder (111) to inject biomass feedstock into the reaction chamber through the air/gas pipe (112) connected to the first feed inlet (124); A high pressure blower (125) draws flue gas from the exhaust outlet (108) of the apparatus after being cooled in a cooler/condenser (145) and also fresh air to provide an air/gas flow which serves as carrier medium through the ejector (123), inlet pipe (112) and feed inlet (124) into the reaction chamber (101b). The flow rates of air and flue gas are regulated by electromagnetic actuator valves (120, 126) and measured by flow sensors (121, 127);

(b) a second feeding system for the combustion chamber having a biomass feedstock storage hopper (128) mounted with a rotary valve feeder (129) at its bottom; an ejector (131) is installed underneath the rotary valve feeder (129) to inject biomass feedstock into the combustion chamber (101a) through the air/gas pipe (132) connected to the feed inlet (134); A high pressure blower (137) draws fresh air and flue gas from the exhaust outlet (108) of the apparatus after being cooled in the cooler/condenser (145) and also fresh air to provide an air/gas flow which serves as carrier medium through the ejector (131), inlet pipe (132, 133) and feed inlet (134) into the reaction chamber (101b). The flow rates of air and flue gas are regulated by electromagnetic actuator valves (138,140) and measured by flow sensors (139,141).

The biomass stored in the storage hoppers (110, 128) can be, but not limited to, wood chips, coffee grounds and crushed oil palm fiber. Preferably, the biomass feeds are preprocessed in pulverized form such that the biomass could be conveyed pneumatically by the air/gas carrier medium during the thermal conversion process.

Sizes of the biomass feed particles up to 25 mm are allowed so as to reduce the material grinding cost. Nevertheless, the particle size is not limited thereto as it depends on the physical properties of the biomass feeds and speed of the air swirling inside the apparatus. The pulverized biomass feeds are pre-dried to a moisture content less than 15% before it is delivered to the storage hoppers (110, 128);

(c) a high efficiency cyclone dust collector (142) for removal of the suspended solid remnants such as ash and char contained in the flue gas or gaseous products such as producer gas or oil vapor, exting from the tubular outlet (108) of the apparatus. The flue gas or gaseous products enter the cyclone dust collector where the fine solid particles are collected and discharged through the outlet (143); and

(d) a water cooled condenser (145) having its inlet connected to the exit of cyclone dust collector (144) for cooling the flue gas, producer gas down to 80°C and condensing steam to water or fuel vapour to liquid bio-oil.

In yet another embodiment of the invention, the apparatus works in collaboration with a programmable logic controller (PLC) system for automated operation and effective control of the operating parameters, viz., temperature, pressure and air/fuel ratio to maintain a stable and consistent operating condition during the thermal conversion process. The air/fuel ratio in the present invention refers to ratio of biomass feedstock to air, in which the air may be a combination of fresh air and composition of the gas recovered from the condenser.

A number of measuring devices are added to the apparatus for optimization of operation by effective controlling and monitoring the process variables, such as but not limited to, temperature, pressure, blown gas flow rate and biomass feeding rate. A pair of thermocouples (117a, 117b), preferably K-type, is installed at the cylindrical sidewalls (102a, 102b) to measure respective process temperatures in the reaction chamber (101b) and the combustion chamber (101a). In addition, a pressure sensor (117b) is installed at the outlet (108) to measure the pressure at the outlet (108) where flue gas or gaseous product is discharged.

The feeding rate of biomass feedstocks to the reaction chamber and combustion chamber can be measured by the rotational speed of the rotary valve feeder by rotary speed encoders (119, 130) mounted onto the shaft of the rotary valve feeders (119, 130). Further, the respective flow rates of air and flue gas are measured by a plurality of flow sensors (120, 121, 127, 139, 141) and regulated by electromechanical actuator valves (120, 126, 138, 140). Preferably, electromechanical actuator valves are located before the flow sensors.

All sensors are connected to the input terminals of a programmable logic controller (PLC), where output signals from the sensors are processed according to a pre-defined algorithm for optimizing the combined operations of the apparatus by monitoring and controlling the process variables, namely, temperature, pressure and air/fuel ratio (referred to as ratio of mass flow rate of air to that of biomass feedstock) through regulating the rotational speed of the rotary valve feeders (111, 129) and the deflection angle of the electromechanical actuator valves (120, 126, 138, 140) with output signals from the PLC.

Hereinafter, operation of the aforementioned apparatus is described in detailed, with reference to Figure 6.

Before starting the operation, the combustion chamber (101a) is heated to a first temperature, preferably 300°C, using an oil or gas burner mounted at the inlet (134). Upon reaching the desired temperature, the biomass feedstock, which is pre-processed by pulverizing to sizes less than 25mm and pre-dried to moisture content less than 15% is fed from the storage hopper (128) of the second feeding system to the combustion chamber (101a) through the rotary valve feeder (129). With the use of the ejector (131), the biomass is injected by a flow of blown gas at speed of 15 to 25 m/s into the bottom section of combustion chamber (101a) through the second feed inlet (134), forming a high-speed vortex of mixture of gas and biomass particles therein. The blown gas is a mixture of air and flue gas. The flue gas, which contains mainly carbon dioxide with low oxygen content, is drawn from the exhaust outlet (108) of the apparatus and cooled down to 80 ºC in a cooler/condenser (145) before supplying to the combustion chamber (101a) to keep the temperature below 800ºC and prevent fusion of ash from damaging the internal walls of the combustion chamber. The flow rate of blown gas can be regulated by the electromagnetic valves (138, 140) which are in turn monitored by the PLC with signals feedback from the flow sensors (139, 141) and thermocouple (117a).

The vortex of mixture of air, flue gas and feedstock swirls inside the combustion chamber (101a) and keeps the feedstock in constant collision and abrasion with the heated walls (102a, 106a) under the action of centrifugal force generated by the cyclonic motion of vortex. It thus enhances the heat transfer rate between the feedstock and heated walls. The feedstock ignites when contacts with the heated walls and burns spontaneously. The temperature inside the combustion chamber (101a) is controlled and maintained at a preset value by the PLC by regulating the rotating speed of rotary valve feeder (129) with the signals feedback by the thermocouple (117a) and the rotational speed sensor (130). The PLC also processes the signals from the air flow sensor (139) and the rotational speed sensor (130) by executing an algorithm to keep the air/fuel ratio slightly exceeding 6, depending on the type biomass feedstock, to allow complete combustion in the combustion chamber (101a). The hot gas generated in the combustion chamber (101a) is forced to enter the reaction chamber (101b) through the rectangular perforations in the annular plate (136) to supply heat required by the reaction chamber (101b, 105) for thermal or thermochemical conversion of feedstock therein.

When the side wall (102b) of the outer inverted cyclone is heated to 300°C, the biomass feedstock is fed from the storage hopper (110) through the rotary feeder (111) to the ejector (112) through which the feedstock is injected by an air/gas flow supplied by the high pressure blower (134) through the inlet pipe (112) and first feed inlet (124) into the reaction chamber (101b). The high pressure blower (134) supplies also a flow of air-gas serving as carrier medium of the feedstock into the outer inverted cyclonic reaction chamber (101b) through the inlet pipe (122) and feed inlet (124) at speed of 15 to 25 m/s. Subsequently, a cyclonic vortex of air-gas-biomass mixture is developed and swirls upwards. Upon reaching the tapered top (104) of the outer cyclone structure (101b), the upward vortex, containing a mixture of gas, solid remnants and possibly some unconverted biomass particulates, is being forced to move downwards into the inner cyclone structure (105) through the top opening (107). The unconverted biomass particulates collide more frequently with the heated cylindrical sidewalls (106a, 106b) to further enhance the thermal conversion rate due to increased swirling speed of vortex in the inner cyclone structure. The solid products, solid remnants such as ash or char are separated from the gaseous products under the action of centrifugal force generated by the cyclonic motion of vortex and discharged through the exit opening (109) of the inner cyclone structure (105) to the discharging screw conveyor (115) and finally into the waste chamber (116). On the contrary, the gaseous product such as non-condensable gases, oil vapor or producer gas reverse its direction to swirl upwards until it finally exits through the outlet (108) at the top of the apparatus. Preferably, the outlet (108) is having a pressure lower than the inner cyclone structure (105) to allow the gases produced to discharge through it.

On swirling through the reaction chamber, biomass feedstock is kept in constant collision and abrasion with the hot walls (102b, 106b) under the centrifugal force generated by the cyclonic motion of vortex. The actions of collision and abrasion of the biomass against the hot walls enhance the rate of heat transfer and thereby speed up the thermal conversion process and at the same time reduce the sizes of feedstock particulates by scraping away the ash or char formed on the surfaces.

The feeding rate of feedstock is so controlled to allow complete thermal or thermochemical conversion on reaching the lower tapered section of the inner cyclone structure (105) wherefrom the vortex reverses in direction and swirls upwards, releasing the gaseous products or non-condensable gases through an outlet pipe (108) while solid products or solid remnants such as ash or char is separated from the vortex and discharged through second opening (109) and rotary valve feeder (114) to the discharging screw conveyor (115).

According to the preferred embodiment of the invention, various thermal or thermochemical conversion processes, namely, torrefaction, pyrolysis and gassification, can be taken place inside the apparatus by executing the algorithm of PLC which contains well defined instructions for processing and monitoring the process variables according to the requirements of the operating conditions of the apparatus to perform as torrefaction reactor, bio-oil reactor or gasifier.

During the operation, the process variables, which include temperature, pressure and air/fuel ratio, are so controlled by the PLC system to maintain consistent product quality and high productivity for performing the three different functions of apparatus:
(i) Maintaining temperatures of torrefaction between 250 to 350°C and air/fuel ratio at 0.4 to 0.8 for torrefaction reactor;
(ii) maintaining temperatures of pyrolysis between 500 to 600°C and air/fuel ratio at 0.13 to 0.18 for bio-oil reactor and
(iii) Maintaining temperatures of gasification between 850 to 950°C and under the sub-stoichiometric conditions with air/fuel ratio from 1.5 to 1.8 for gasification.

In the case when the apparatus is used as a torrefaction reactor, the biomass feedstock, being carried along in the vortex, is heated up rapidly by the hot sidewalls (102b, 106b) within fraction of a second to 350°C to set off the torrefaction process as it swirls upwards in the vortex in the outer cyclone structure (101b). On reaching the tapered top (104), it reverses in direction and swirls downwards in the inner cyclone structure (105) and finally discharges through the second opening (109) to the rotary valve feeder (114) and water-cooled discharging screw conveyor (115) to the collection chamber (116). The steam and flue gas swirl upwards from the tapered section of the inner cyclone structure (105) to exit through the outlet (108) and enter into the cyclone dust collector (142) where the fine particulates are separated out and discharged through the outlet (143). The cleaned steam and flue gas exit through the outlet (144) and enter the cooler/condenser (142) where the flue gas is cooled down to 80°C before finally exit through the outlet (147) while the steam is condensed to water and discharged through the outlet (146). Portion of the flue gas is drawn from the outlet (147) through the pipeline (148) by the blower (125) to the feed inlet (124) of the reactor to serve as carrier medium of the feedstock.

The solid product produced from torrefaction reactor is a partially carbonized solid containing most of the volatile components of the biomass. It is a stable, brittle, water resistant (hydrophobic) and biologically non-degradable in storage. The calorific value varies from 5500 to 6500 kcal/kg, depending on the degree of carbonization of the product.

For thermochemical conversion of biomass to bio-oil, the feedstock is preferred to be torrefied to get rid of moisture and pyro ligneous acid contents.

In the case when the apparatus is used as a bio-oil reactor, the biomass feedstock, being carried along by the vortex, is heated up rapidly by the hot sidewalls (102b, 106b) at a rate of ~103K/s to 600°C set off the pyrolysis process and releases the volatile matters as liquid vapour as it swirls upwards in the outer cyclone structure (101b). On reaching the tapered top (104). the vortex reverses its direction downwards and then upwards again upon reaching the tapered section of the inner cyclone structure (105) and finally exits through the outlet pipe (108) as flue gas and oil vapour. The ash and char are separated out from the vortex flow and discharged through the second opening (109) to the rotary valve feeder (114) and water-cooled discharging screw conveyor (115). The flue gas and oil vapors are drawn to the cyclone dust collector (142) where the fine particulates are collected and discharged through outlet (143). The clean flue gas and oil vapour exit through the outlet (144) and enter the cooler/condenser (145) where the oil vapor is condensed to bio-oil and discharged through the outlet (146) while the flue gas is cooled down to 80°C and exits through the outlet (147).

The bio-oil is a black liquor comprising 20 to 25% of water, 25 to 30% water insoluble pyro lytic lignin, 5 to 12% organic acids, 5 to 10% non-polar hydrocarbons, 5 to 10% anhydrosugars and 10 to 25% of other oxygenated compounds. The calorific value of the liquid fuel is typically 16,700 to 18,000 kJ/kg.

In the case when the apparatus is used as a gasifier, the biomass feedstock, being carried along by the vortex, is heated up rapidly by the hot sidewalls (102b, 106b) at a rate of ~103K/s to ~900°C to set off the gasification process. The fine particles biomass feedstock are rapidly pyrolyzed, combusted and gasified whereas the coarser or unconverted particulates are carried along by the high speed vortex to swirl upwards in the outer cyclone (101b) and reverse in direction upon reaching the tapered top (104) to swirl down into the inner cyclone (105) through the open top (107). The vortex swirls upwards again upon reaching the tapered section of the inner cyclone (105) and finally exits through the outlet pipe (108) as producer gas. The ash and char is separated out from the vortex flow and discharged through the second opening (109) to the rotary valve feeder (114) and water-cooled discharging screw conveyor (115) to the collection chamber (116). The producer gas is drawn into the cyclone dust collector (142) to separate out the fine particulates and discharge through outlet (143). The cleaned producer gas exits through the outlet (144) and enters the cooler/condenser (145) where excess steam is condensed to water and collected through the outlet (146) and the producer gas is cooled down to 80°C and exits through the outlet (147).

The producer gas is composed of 18 to 30% of carbon monoxide, 2 to 7% of hydrogen, 0.2 to 0.9% of methane, 55 to 65% of nitrogen, 0.3 to 1.3% of oxygen and 4 to 14% of carbon dioxide. The carbon monoxide and hydrogen content can be kept at a consistently high calorific value of 5000 kJ/kg by maintaining the air-to-biomass ratio at an optimum value as well as the temperature at appropriate values.

It should be noted that the combustion chamber (101a) is required to be used only for heating up purpose at the starting of gasifier and is shut down during normal operation. It should also be noted that no recycle of flue gas from the outlet of cooler/condenser (147) through the branch pipe (148) is necessary when the apparatus is operated as a gasifier. The heat required for the gasification process is supplied by combustion of portion of feedstock inside the reactor chamber to sustain the temperature for gasification up to 950°C.

One of the unique features of the embodiment of the patent is enabling longer residence time for a complete conversion process of biomass feeds to the required products. The entrained vortex flow is forced to swirl three times inside the apparatus in opposite directions, increasing the residence time to allow a wider range of acceptable size of biomass feed particles for complete thermal or thermochemical conversion.

The disclosure includes that of the foregoing description as well as that contained in the appended claims. Although this invention has been described in its preferred form with a degree of particularity, it is understood that the disclosure of the preferred form containing many specifications and changes in the details of construction and the combination and arrangements of parts may not to be regarded as a departure from the scope of invention.

CLAIMS

1. An apparatus for producing biofuels from biomass comprising:
a reaction chamber (101b, 105) defined by an integral space formed from an outer inverted cyclone structure (101b), defined by a cylindrical sidewall (102b), an annular base plate (136) fabricated with a radial array of rectangular perforations and a substantially tapered top (104), and
an inner cyclone structure (105), having a cylindrical sidewall (106b), an open top (107) and a substantially tapered bottom section (106a) with an exit opening (109); the outer and inner cyclone structures are arranged in such a way that the inner cyclone structure is enclosed coaxially within the outer cyclone structure and extends downwards from the annular base plate (136);
a combustion chamber (101a), having a cylindrical structure defined by the sidewalls of the outer and inner cyclone structures (101b, 105) and a bottom supporting base (103), disposed underneath the reaction chamber and surrounding the extended tapered bottom (106a) of the inner cyclone structure;
feed inlets (124, 134) mounted tangentially onto the sidewalls (102a, 102b) of the outer cyclone structure and the combustion chamber for infeed of biomass feedstock by blown gas; and
an outlet (108) extending from the tapered top (104) into the upper portion of the second cyclonic structure;
wherein the biomass feedstock is converted in the reaction chamber (101b, 105) to non-condensable gases, bio-oil vapour or solid products separately under predetermined temperatures and air/fuel ratios and wherein the non-condensable gases, bio-oil vapours, solid remnants or unconverted biomass swirl upwards in the outer cyclone structure (101b), then downwards into the inner cyclone structure (105) upon reaching the tapered top (104) of the outer cyclone structure and finally the non-condensable gases or bio-oil vapours swirl upwards from the tapered bottom section (106a) of the inner cyclone structure to exit though the outlet (108) while the solid

products/remnants are discharged through the exit opening (109).

2. An apparatus of claim 1, wherein the biomass is fed by blown gas to form an air/gas-biomass vortex swirling upwards in the outer cyclone structure (101b) to the inner cyclone structure (105).

3. An apparatus of claim 1, wherein the combustion chamber (100a) is functioned such that the biomass feedstock is heated up by constant collision and vigorous abrasion against preheated sidewalls (102a, 106) to generate heat to supply to the reaction chamber through the perforations on the annular base plate (136) for thermal or thermochemical conversion of biomass in the reaction chamber.

4. An apparatus of claim 1, wherein the biomass is converted to solid products at temperatures of 250 to 350°C and air/fuel ratio of 0.4 to 0.8.

5. An apparatus of claim 1, wherein the biomass is converted to bio-oil vapours at temperatures of 500 to 600°C and air/fuel ratio of 0.13 to 0.18.

6. An apparatus of claim 1, wherein the biomass is converted to non-condensable gases at temperatures of 850 to 950°C and air/fuel ratio of 1.5 to 1.8.

7. An apparatus of claim 1 or 4, wherein the solid products are torrified biomass or solid remnants.

8. An apparatus of claim 7, wherein the solid remnants are ash, char or a combination thereof.

9. An apparatus of claim 1, wherein the non-condensable gases are any one or combination of carbon monoxide, hydrogen, methane, nitrogen, oxygen and carbon

dioxide.

10. An apparatus of claim 1 further comprising a solid discharging screw conveyor assembly, connected to the opening (109) at the bottom of the inner cyclone structure (105).

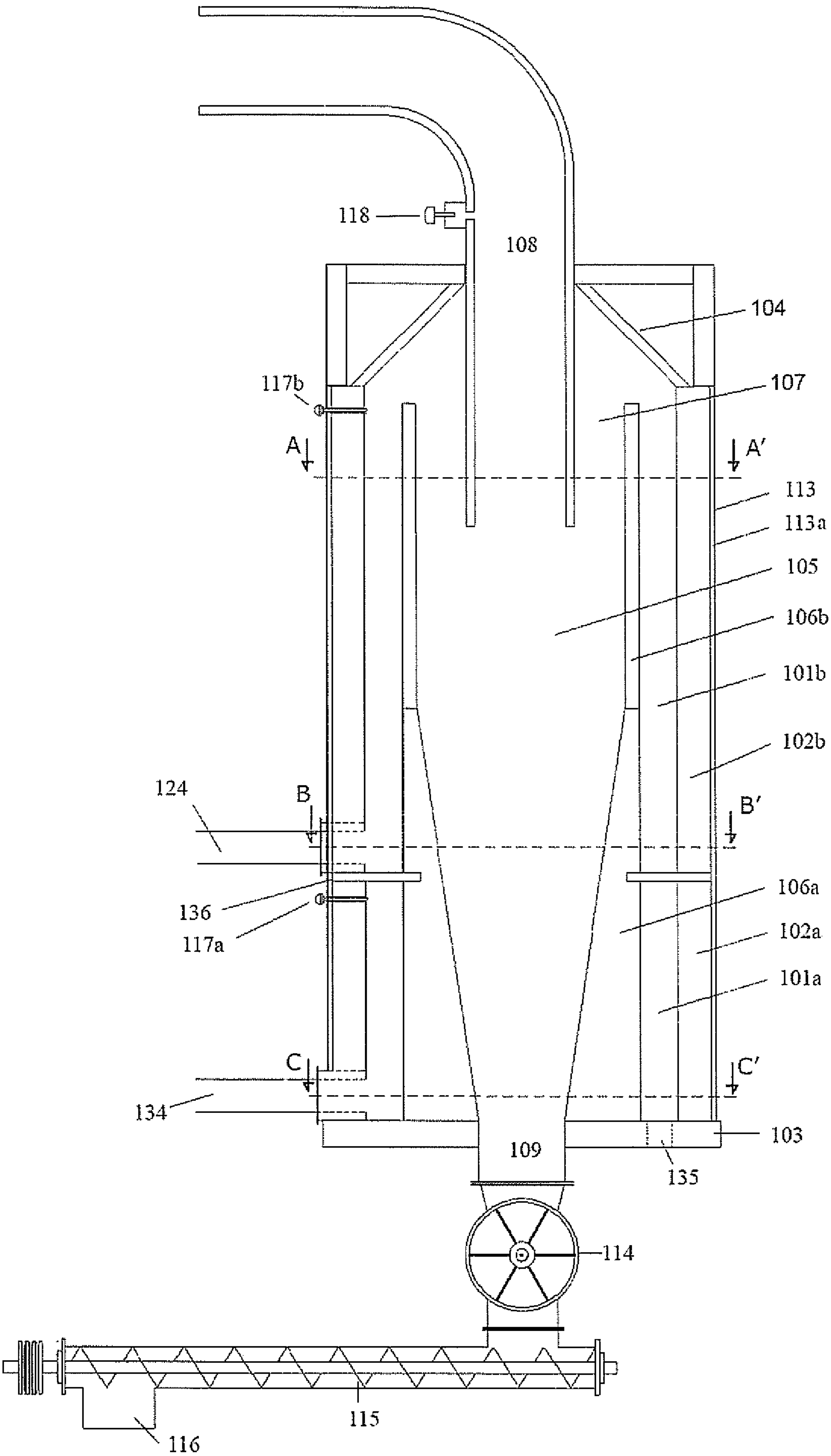
11. An apparatus of claim 1 or 9 further comprising a cyclone dust collector (142) for receiving the non-condensable gases and bio-oil vapour from the outlet for removal of the solid remnants suspended therein.

12. An apparatus of claim 1 or 9 further comprising a cyclone cooler/condenser (145) to reduce the temperature of the non-condensable gases or to condense the bio-oil vapour to liquid bio-oil.

13. An apparatus of claim 1 further comprising a channel (135) at the base (103) of the combustion chamber (101a) to discharge the solid products deposited at the combustion chamber.

14. An apparatus of claim 1, wherein the tapered top (104) of the outer cyclone structure (101b) facilitates to divert the vortex moving downwards into the inner cyclone structure (105) through the open top (107) at an increased whirling speed.

15. An apparatus of claim 1 is used to perform as a torrefaction reactor, a bio-oil production reactor or a gasifier.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116

Figure 1

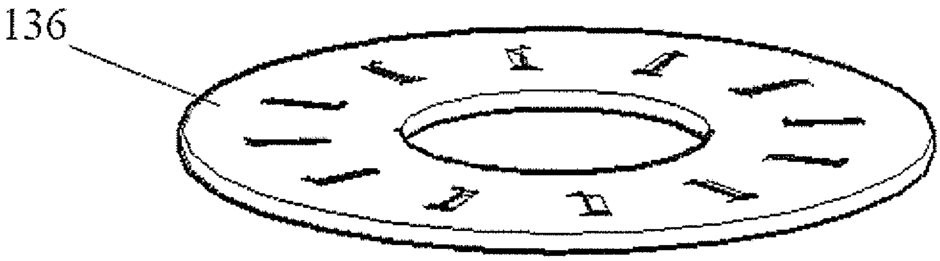

Figure 2

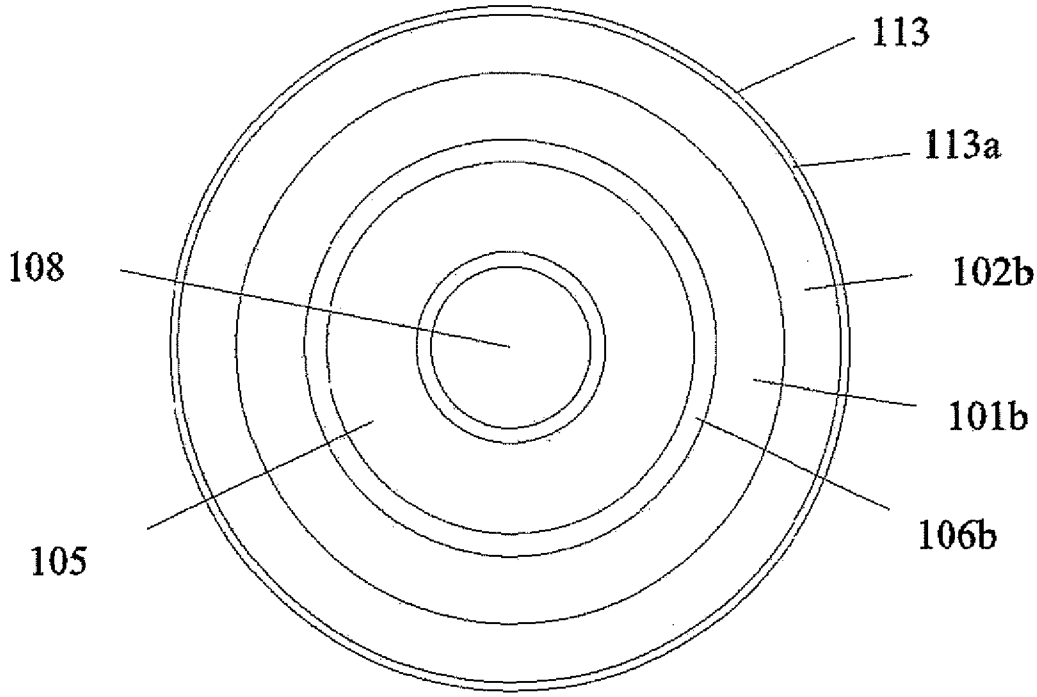

Figure 3

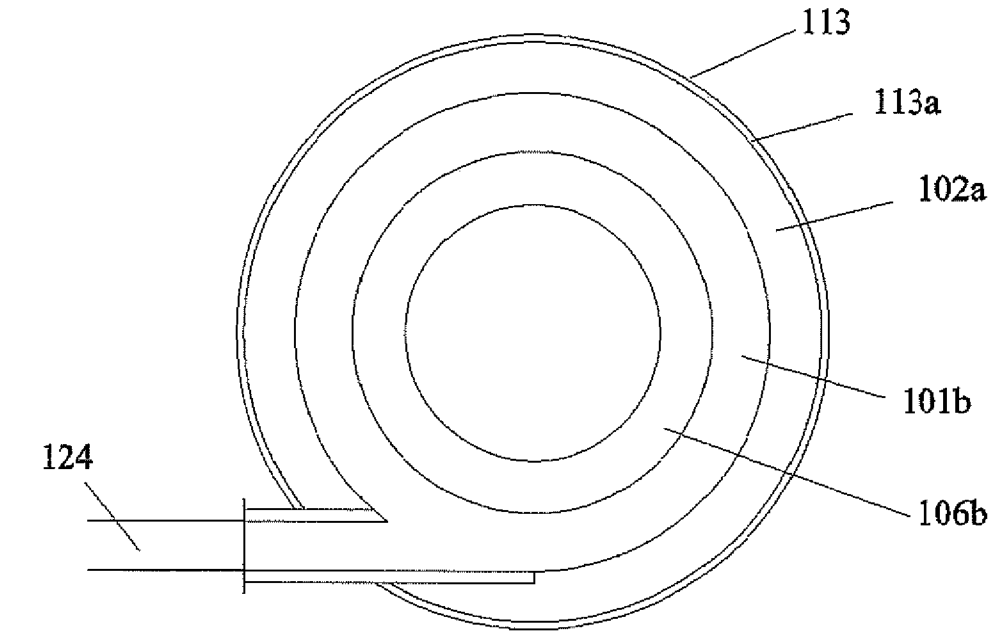

Figure 4

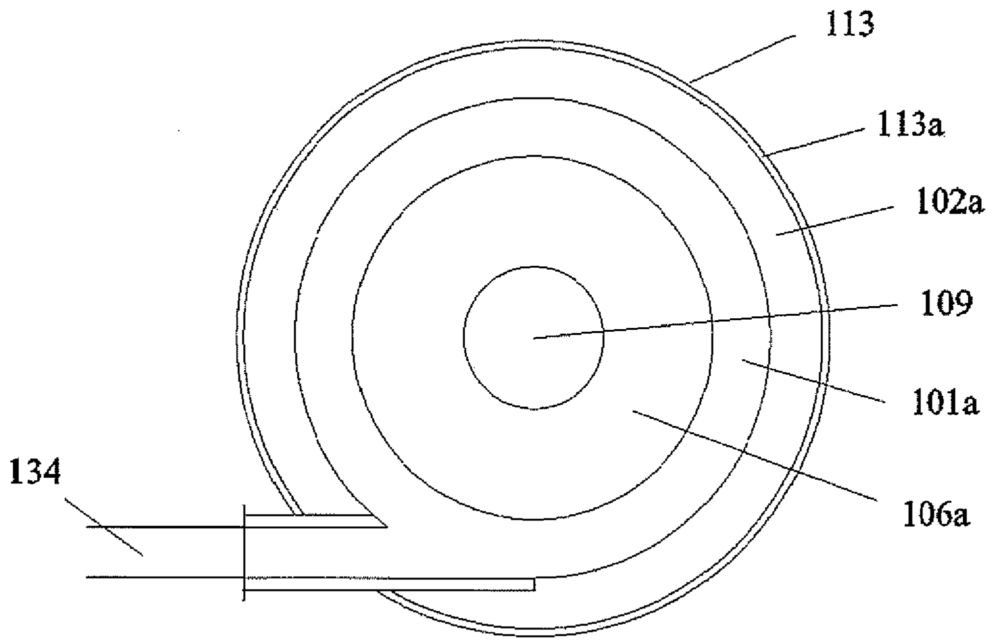

Figure 5

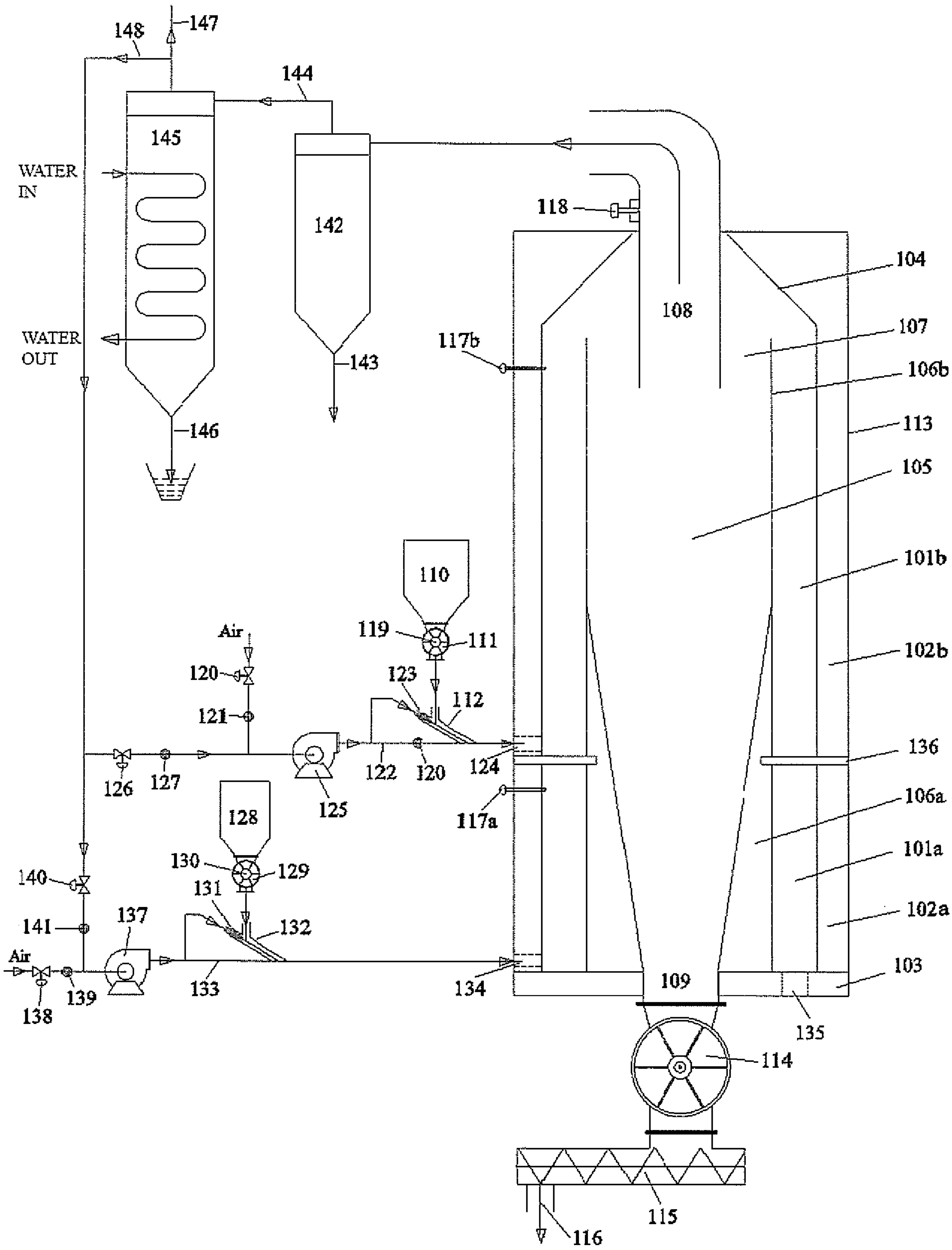
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Fig. 6