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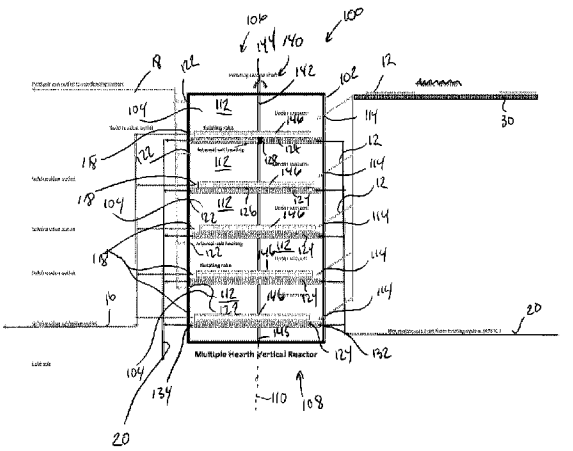
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(54) Titre : SYSTEME ET PROCEDE POUR CONVERTIR LES DECHETS ORGANIQUES EN PRODUITS DESIRABLES AU MOYEN DE LA DECOMPOSITION THERMIQUE

(54) Title: SYSTEM AND PROCESS FOR CONVERTING A WASTE ORGANIC MATERIAL INTO DESIRABLE PRODUCTS USING THERMAL DECOMPOSITION



(57) Abrégé/Abstract:
The present disclosure relates to a system and a process that aim to convert waste organic material, such as waste plastic material, into petroleum products (e.g., diesel, gasoline and kerosene). The system is configured for producing a carbon-based by-product material and purified hydrocarbons-containing gases, from the thermal decomposition of the waste organic material. The system includes a multiple hearth vertical bed reactor configured for pyrolyzing (i.e., thermally decomposing) the waste organic material, at an elevated temperature, and in absence of oxygen, to obtain the carbon-based by-product material and hydrocarbons-containing gases, and a condensation system configured for producing the purified hydrocarbons-containing gases from the hydrocarbons-containing gases. The system described herein can thus find its application in, for example, the recycling of plastics and plastic residues generally comprising several polymers of different grades, or in other fields. Other products of interest can be obtained, while converting a waste biomass material into biochar and an oxygenated compounds-containing liquid material.

ABSTRACT

The present disclosure relates to a system and a process that aim to convert waste organic material, such as waste plastic material, into petroleum products (e.g., diesel, gasoline and kerosene). The system is configured for producing a carbon-based by-product material and purified hydrocarbons-containing gases, from the thermal decomposition of the waste organic material. The system includes a multiple hearth vertical bed reactor configured for pyrolyzing (i.e., thermally decomposing) the waste organic material, at an elevated temperature, and in absence of oxygen, to obtain the carbon-based by-product material and hydrocarbons-containing gases, and a condensation system configured for producing the purified hydrocarbons-containing gases from the hydrocarbons-containing gases. The system described herein can thus find its application in, for example, the recycling of plastics and plastic residues generally comprising several polymers of different grades, or in other fields. Other products of interest can be obtained, while converting a waste biomass material into biochar and an oxygenated compounds-containing liquid material.

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SYSTEM AND PROCESS FOR CONVERTING A WASTE ORGANIC MATERIAL INTO DESIRABLE PRODUCTS USING THERMAL DECOMPOSITION

TECHNICAL FIELD

[0001] The present disclosure relates to systems and processes for converting a waste organic material, such as a waste plastic material, a waste biomass material or a combination thereof, into desirable products such as petroleum products, char, biooils, etc. using thermal decomposition. The present disclosure thus also relates to a bed reactor configured for pyrolyzing the waste organic material to produce a carbon-based by-product material and hydrocarbons-containing gases or alternatively, oxygenated compounds-containing gases. Finally, the present disclosure relates to the field of the treatment of hydrocarbons-containing gases resulting from the thermal decomposition of a waste plastic material.

BACKGROUND

[0002] The annual world production of plastics is estimated at 300 million of tons, with an annual growth rate of about 4%. Of these 300 million of tons of plastics produced annually, only around 5% are recycled. A portion of these waste plastics is put in landfill, while another portion is incinerated. Unfortunately, a significant portion of the buried waste plastic residues end up in the environment and as known, its degradation can take several years. On the other hand, incineration involves a process that increases greenhouse emissions.

[0003] Pyrolysis has become an attractive solution to treat the waste plastic residues, or other biomass residues, so as to produce desirable products such as, carbon-based by-products and hydrocarbons-containing gases. Indeed, thermal decomposition (i.e., pyrolysis) enables a large variety of solid and semi-liquid waste to be transformed into useful products. In operation, the plastic or biomass residues are fed through the reactor and heated, at an elevated temperature, and in the absence of oxygen, so as to produce solid carbon-based residues and hydrocarbons-containing gases. Vacuum pyrolysis is often chosen over atmospheric pyrolysis and can typically be carried out at a temperature of between about 400 °C and about 500°C and at a total pressure of between about 10 kPa and just below atmospheric pressure, i.e., 100 kPa. These vacuum conditions allow the

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pyrolysis products to be rapidly withdrawn from the hot reaction chamber of the pyrolysis reactor.

[0004] A major limitation of vacuum pyrolysis technologies remains heat transfer. Indeed, previous studies have shown that the heat transfer rate is essentially the main limitation for pyrolysis reactions to occur efficiently. More particularly, conventional vacuum pyrolysis reactors, such as multiple hearth furnaces, rotary kilns and screw type reactors, exhibit overall heat transfer coefficients ranging from about 10 to about 60 W/[m^2.°K], depending on the type of feedstock being fed therethrough. Multiple factors can limit the heat transfer to occur between the fed particles and a multiple hearth vertical bed reactor.

[0005] First off, the low thermal conductivity of the feedstock residues can partially explain why the heat transfer rate is that low. Additionally, since the supporting trays or floors on which the particles are supported are heated only by radiation (the reactor housing transfers heat by radiation towards the supporting trays), the heat transfer coefficient in the traditional multiple hearth furnace is limited both by the unfavourable view factor and the minimal conduction between the heated supporting trays and the residues to be heat treated.

[0006] Another limitation arises from the type of agitation system used in the multiple hearth vertical bed reactors. Indeed, each supporting tray arranged inside the multiple hearth vertical bed reactor is usually equipped with a series of radial metal bars which convey the feedstock particles as they move over the trays. The feedstock particles tend to accumulate along these bars, thus leaving almost 50% of the heated trays uncovered by the feedstock particles, which renders the heat transfer inefficient.

[0007] There is therefore a need for a system and process that can convert efficiently a waste organic material into desirable products using thermal vacuum pyrolysis, which, by virtue of their designs and components, would be able to overcome or at least minimize some of the above-discussed concerns. There is also a need for a multiple vertical bed reactor having a configuration that increases heat transfer between the supporting trays and the waste organic residues being fed thereon, but also between the hot carbon-based residues produced by the pyrolysis reaction and the cooler residues introduced into the hot chamber of the multiple hearth vertical bed reactor.

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SUMMARY

[0008] It is an object of the present disclosure to provide a system and a process for converting a waste organic material, such as a waste biomass material or a waste plastic material, into char and/or petroleum or oxygenated liquid products, that overcome or mitigate one or more disadvantages of known systems and processes, or at least provide useful alternatives.

[0009] It is another object of the present disclosure to provide a multiple hearth vertical bed reactor for thermally decomposing (i.e., pyrolyzing) the waste organic material, to obtain a carbon-based by-product material and hydrocarbons-containing gases, or alternatively, oxygenated compounds-containing gases, that overcomes or mitigates one or more disadvantages of known pyrolysis reactors, or at least provides useful alternatives.

[0010] It is another object of the present disclosure to provide a system and a process for treating the hydrocarbons-containing gases resulting from a pyrolytic or thermal decomposition of a waste organic material comprising a polymer or a mixture of polymers, to recover one or more hydrocarbon(s) contained in the hydrocarbons-containing gases.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Other objects, advantages and features will become more apparent upon reading the following non-restrictive description of embodiments thereof, given for the purpose of exemplification only, with reference to the accompanying drawings in which:

[0012] Figure 1 shows a flow diagram of a system for converting a waste organic material, such as a waste biomass material or a waste plastic material, into char and/or liquid products, according to a non-limitative embodiment, where the system includes a multiple hearth vertical bed reactor and a condensation system in fluid communication with the multiple hearth vertical bed reactor, downstream thereof;

[0013] Figure 2 is a schematic cross-sectional view of a multiple hearth vertical bed reactor in accordance with a non-limitative embodiment, where waste biomass residues are fed through the multiple hearth vertical bed reactor;

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[0014] Figure 3 is a schematic view of a multiple hearth vertical bed reactor in accordance with another non-limitative embodiment, where waste plastic residues are fed through the multiple hearth vertical bed reactor;

[0015] Figure 4 is a top perspective view of a multiple hearth vertical bed reactor in accordance with a non-limitative embodiment, the reactor having two vertically aligned hearths; and

[0016] Figure 5 is a top plan view of a supporting tray of a multiple hearth vertical bed reactor in accordance with a non-limitative embodiment.

DETAILED DESCRIPTION

[0017] In the following description, the same numerical references refer to similar elements. Furthermore, for the sake of simplicity and clarity, namely so as to not unduly burden the figures with several reference numbers, not all figures contain references to all the components and features, and references to some components and features may be found in only one figure, and components and features of the present disclosure which are illustrated in other figures can be easily inferred therefrom. The embodiments, geometrical configurations, materials mentioned and/or dimensions shown in the figures or described in the present disclosure are embodiments only, given solely for exemplification purposes.

[0018] Furthermore, in the context of the present description, it will be considered that all elongated objects will have an implicit "longitudinal axis" or "centerline", such as the longitudinal axis of a shaft for example, or the centerline of a biasing device such as a coiled spring, for example, and that expressions such as "connected" and "connectable", "secured" and "securable", "engaged" and "engageable", "installed" and "installable" or "mounted" and "mountable", may be interchangeable, in that the present multiple hearth vertical bed reactor or system also relates to kits with corresponding components for assembling a resulting fully-assembled and fully-operational multiple hearth vertical bed reactor or system.

[0019] Moreover, components of the multiple hearth vertical bed reactor, system and/or steps of the process(s) described herein could be modified, simplified, altered, omitted and/or interchanged, without departing from the scope of the present disclosure, depending on the particular applications which the present multiple hearth vertical bed reactor or

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system is intended for, and the desired end results, as briefly exemplified herein and as also apparent to a person skilled in the art.

[0020] In addition, although the embodiments as illustrated in the accompanying drawings comprise various components, and although the embodiments of the multiple hearth vertical bed reactor or system and corresponding portion(s)/part(s)/component(s) as shown consist of certain geometrical configurations, as explained and illustrated herein, not all of these components and geometries are essential and thus should not be taken in their restrictive sense, i.e. should not be taken so as to limit the scope of the present disclosure. It is to be understood, as also apparent to a person skilled in the art, that other suitable components and cooperation thereinbetween, as well as other suitable geometrical configurations may be used for the present multiple hearth vertical bed reactor, system and corresponding portion(s)/part(s)/component(s) according to the present multiple hearth vertical bed reactor or system, as will be briefly explained herein and as can be easily inferred herefrom by a person skilled in the art, without departing from the scope of the present disclosure.

[0021] To provide a more concise description, some of the quantitative and qualitative expressions given herein may be qualified with the terms "about" and "substantially". It is understood that whether the terms "about" and "substantially" are used explicitly or not, every quantity or qualification given herein is meant to refer to an actual given value or qualification, and it is also meant to refer to the approximation to such given value or qualification that would reasonably be inferred based on the ordinary skill in the art, including approximations due to the experimental and/or measurement conditions for such given value.

[0022] It is noted that the terms “pyrolysis”, “decomposition” or “thermal decomposition” are used herein interchangeably for the thermochemical decomposition of a waste organic material, for example, of a waste biomass material or of a waste plastic material, at an elevated temperature in absence of oxygen to produce a carbon-based by-product material (e.g., biochar) and hydrocarbons/oxygenated compounds-containing gases. The terms “biochar” and “char” can be used herein interchangeably for the term “carbon-based by-product material” or “carbonaceous pyrolysis by-product material”.

[0023] The term “condensation” means the change of state of a compound passing from a gaseous state to a liquid state.

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[0024] The term "vaporization" is understood to mean the change of state of a compound passing from a liquid state to a gaseous state.

[0025] For the purposes of the present disclosure, the term "condensate" will be understood to mean a mixture of compounds obtained at the end of a condensation step or stage. This mixture can include one or more hydrocarbons(s) and an absorbent liquid which has been involved, in particular by heat exchange, in the condensation of the hydrocarbon(s).

[0026] The term "hydrocarbons-containing gases" is understood to mean a reaction product resulting from the thermal decomposition of the waste organic material, such as waste plastic material, and includes the hydrocarbons, and other by-products.

[0027] The present disclosure relates to a system and a process that aim to convert waste organic material, such as waste plastic material or waste biomass material, into char, petroleum products (e.g., diesel, gasoline and kerosene) or alternatively, biooils. The waste plastic material can include, for example, high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), or a combination thereof. On the other hand, the waste biomass material can include, for example, wood or forest residues, waste from food crops (e.g., wheat straw, bagasse, almond shells, etc.), horticultural waste, food waste, animal farming waste, or a combination thereof.

[0028] Indeed, a system and a process for producing a carbon-based by-product material and purified hydrocarbons-containing gases, or alternatively, purified oxygenated compounds-containing gases, from the thermal decomposition of a waste organic material, for the production of petroleum products or oxygenated compounds-containing liquid material for example, are described herein. The system at least includes a multiple hearth vertical bed reactor for pyrolyzing (i.e., thermally decomposing), under reduced pressure conditions for example, the waste organic material, at an elevated temperature, and in absence of oxygen, to obtain the carbon-based by-product material and hydrocarbons-containing gases, or alternatively, oxygenated compounds-containing gases, and a condensing unit to produce the purified hydrocarbons-containing material and an acetic aqueous material from the hydrocarbons-containing gases, as described in more details below. For example, a waste biomass material can lead to an oxygenated oil containing a small amount of water and to an aqueous phase containing acetic acid, phenols, aldehydes, and ketones. The waste biomass material will also lead to gases with oxygenated

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compounds such as oxygenated C2-C5 compounds and methane, and finally, biochar. On the other hand, a plastic material will lead to liquid hydrocarbons and hydrocarbons-containing gases and solid residues (with the presence of a small water phase).

[0029] In one scenario, the multiple hearth vertical bed reactor can include a longitudinally-extending housing which defines a plurality of internal chambers (the internal chambers can be isolated from one another or can be in solid matter/gas communication), at least one housing waste inlet which extend through the longitudinally-extending housing for admitting the waste organic material into the housing (in a particular embodiment, the reactor includes a plurality of housing waste inlets for admitting the waste organic material into the plurality of internal chambers), at least one housing product outlet which extend through the longitudinally-extending housing for discharging the carbon-based by-product material out of the internal chambers (in a particular embodiment, the reactor includes a plurality of housing product outlets to discharge the carbon-based by-product material out of the plurality of internal chambers) and at least one housing gas outlet which extend through the longitudinally-extending housing, for discharging the hydrocarbons-containing gases (or alternatively, the oxygenated compounds-containing gases) out of the plurality of internal chambers (once again, in a particular embodiment, the reactor includes a plurality of housing gas outlets, at upper portions of the internal chambers for discharging the hydrocarbons-containing gases, for example, out of the plurality of internal chambers). In one implementation, where a waste biomass material is fed through the multiple hearth vertical bed reactor for example, the plurality of internal chambers can be operated in parallel (i.e. as a distinct unit from the other internal chambers), and each internal chamber can have its respective housing inlet, housing outlet and/ housing gas outlet, for example. However, in another scenario, where a waste plastic material is fed through the multiple hearth vertical bed reactor for example, the plurality of internal chambers can be operated in series (i.e. with waste organic material, carbon-based by-product material, and gases flowing from one internal chamber to the next one), and the multiple hearth vertical bed reactor can include a single housing inlet, a single housing outlet as well as a single housing gas outlet, as described in more details below. It is appreciated that combinations thereof can be designed. For instance, the reactor can include a plurality of housing waste inlets and a plurality of housing product outlets but a single housing gas outlet wherein gas withdrawn from each of the internal chambers is discharged from the reactor housing. Since the reactor is vertically

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oriented, i.e. the internal chambers are vertically-superposed, less surface area is required to implement the system described herein. Scale up of the reactor is also more convenient.

[0030] The multiple hearth vertical bed reactor can further include a plurality of supporting trays which are disposed horizontally inside the longitudinally-extending housing and spaced-apart from one another along a housing longitudinal axis. In an embodiment, each one of the internal chambers includes one of the supporting trays. It is appreciated that, in an alternative embodiment, the internal chambers can include one or more supporting trays. Each supporting tray is shaped, sized and configured so as to support the waste organic particles to be heat treated and/or the carbon-based by-product particles produced and to heat the waste organic particles at a temperature that will allow a pyrolysis reaction to occur in the longitudinally-extending housing, and more particularly, that will allow pyrolysis reactions to occur in the plurality of internal chambers (e.g., where biomass particles are fed through the reactor), so as to produce the carbon-based by-product material or particles and the oxygenated compounds-containing gases, or alternatively, the hydrocarbons-containing gases.

[0031] In one implementation of the multiple hearth vertical bed reactor, each supporting tray can define a tray support surface for supporting the waste organic material and the produced carbon-based by-product material thereon as well as at least one molten salt-receiving channel that has a channel inlet and a channel outlet. Each molten salt-receiving channel is configured to allow a flow of a heat carrier molten salt material, capable of heat transfer to the supporting tray, therethrough and between the channel inlet and the channel outlet. The multiple hearth vertical bed reactor described herein thus uses an indirect heating system, involving heat carrier molten salts which flow inside molten salt-receiving channel(s) of the supporting trays, to heat the feedstock supported thereon by both conduction and radiation. The temperature can thus remain substantially constant throughout the reactor, improving the heat transfer between the trays and the particles (i.e. the waste organic material and the produced carbon-based by-product material).

[0032] The multiple hearth vertical bed reactor can also include a conveying and agitating system disposed inside the longitudinally-extending housing for mixing together the waste organic material and the produced carbon-based by-product material on the tray support surface and for displacing the produced carbon-based by-product material along a

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predetermined conveying direction on the tray support surface and towards the housing outlet(s), as described in more details below. The conveying and agitating system agitates the feedstock during the thermal decomposition reaction, which can greatly increase the heat transfer between the multiple heart vertical bed reactor and the feedstock.

[0033] As described in more details below, the system can further include a condensation system for treating the hydrocarbons-containing gases resulting from the pyrolytic decomposition of a waste plastic material. The system and process described herein can thus find their application in the recycling of plastics and plastic residues generally comprising several polymers of different grades, but also in other fields. As mentioned above, the waste biomass material will produce at the end only a small amounts of light hydrocarbons. Gases obtained in a greater amount will include CO_2 and CO. On the other hand, waste plastic material will produce at the end hydrocarbons-containing gases having a heat of combustion that is closed to the heat of combustion of natural gas. Almost all organic vapors will be condensed in liquids such as diesel, kerosene and gasoline (after a distillation stage).

[0034] Referring now to the drawings and more particularly to the non-limitative embodiment of Figure 1, a system 10 for producing a low water-content hydrocarbons-containing material (when plastic material is involved) or an oxygenated compounds-containing liquid material (when biomass material is involved) and a carbon-based by-product material 16 from the thermal decomposition of a waste organic material 12 is provided. The system 10 includes a multiple hearth vertical bed reactor 100 for pyrolyzing the waste organic material 12 to produce the carbon-based by-product material 16 and hydrocarbons gases, or alternatively, oxygenated compounds-containing gases 18, a reactor heating system 200 for providing heat to the multiple hearth vertical bed reactor 100 and thus, to the waste organic material 12, via heat carrier molten salts, a condensing unit, in fluid communication with the reactor 100, for condensing the produced hydrocarbons-containing gases 18 to produce purified hydrocarbons-containing gases 26 and a non-vaporized liquid 28, as well as a separation unit, a distillation column for example, to separate into different fractions the purified hydrocarbons-containing gases 26. Still referring to the non-limitative embodiment of Figure 1, the waste organic material 12 can be fed to the multiple hearth vertical bed reactor 100 from a feeding system 30. The waste organic material 12 can include waste plastic residues containing polymers such as high-density

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polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), other biomass residues or any combination thereof. It is noted that the waste organic material 12 can also include an amount of water.

Multiple hearth vertical bed reactor

[0035] Now referring more particularly to the non-limitative embodiment of Figure 2, there is shown in more details a multiple hearth vertical bed reactor 100. The multiple hearth vertical bed reactor 100 includes a longitudinally-extending housing 102 which defines a plurality of internal chambers spaced-apart from one another along a housing longitudinal axis. For example, the longitudinally-extending housing 102 can be lined with fire brick or simply isolated with other heat resistant material and can have a cylindrical configuration. The longitudinally-extending housing 102 extends between housing longitudinal ends 106, 108 and is divided into a plurality of vertically aligned hearths 104, the number of hearths 104 being preselected depending on the particular process being carried out.

[0036] The multiple hearth vertical bed reactor 100 further includes a plurality of housing inlets 114, which extend through the longitudinally-extending housing 102, for admitting the waste organic material 12 or particles into the plurality of internal chambers 112, a plurality of housing outlets 118, which extend through the longitudinally-extending housing 102, for discharging the carbon-based by-product material 16 or particles out of the plurality of internal chambers 112, as well as one or more gas outlet(s) 122, which extend(s) through the longitudinally-extending housing 102, at an upper portion thereof, or alternatively, at corresponding upper portions of the vertically aligned hearths 104, for discharging the hydrocarbons-containing gases or oxygenated compounds-containing gases 18 formed during the thermal decomposition reaction out of the plurality of internal chambers 112. The housing gas outlet(s) 122 can be connected via a vacuum pump or blower to the condensation system 300, as describe below, when the material is subjected to vacuum pyrolysis in the reactor. The reactor 200 can operate under a reduced pressure of between about 1 and about 2 inches of water. This operating pressure avoids escape of odorous gases out of the reactor 200, while minimizing ambient air leaking inside the reactor 200. A base 32 can also be provided to support the longitudinally-extending housing 102.

[0037] Referring to the non-limitative embodiments of Figures 2 to 5, the multiple hearth vertical bed reactor 100 further includes a plurality of supporting trays or floors 124 which

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are disposed horizontally inside the longitudinally-extending housing 102 and spaced-apart from one another along the housing longitudinal axis. For example, each supporting tray 124 can be secured to an internal portion of the longitudinally-extending housing 102. Each supporting tray 124 is configured for supporting the waste organic material 12 (i.e., the bed of waste organic particles or molten material) fed through the plurality of internal chambers 112, and to heat the waste organic particles to a temperature that allows pyrolysis thereof, to produce the carbon-based by-product material 16 and the hydrocarbons-containing gases or oxygenated compounds-containing gases 18. The supporting trays 124 thus, together with the longitudinally-extending housing 102, define the plurality of hearths 104. Each supporting tray 124 defines a tray support surface 126 for supporting the waste organic material 12 and the produced carbon-based by-product material 16 thereon, and molten salt-receiving channels that have a channel inlet and a channel outlet. The molten salt-receiving channels are shaped, sized and configured to allow flow of a heat carrier molten salt material 20, which is capable of heat transfer to the supporting tray 124, therethrough and from the channel inlet towards the channel outlet. A person skilled in the art to which the multiple hearth vertical bed reactor 100 pertains would however understand that each supporting tray 124 can have one or more molten salt-receiving channel(s) and can take any shape, size or configuration, providing heat transfer between the heat carrier molten salt material and the tray support surface 126, and thus, the waste organic particles. In one implementation, baffles can be used to form the channels inside the supporting trays 124. The supporting trays 124 are made of a conductive material that promotes heat transfer. Optionally, the multiple hearth vertical bed reactor 100 can be provided with one or more burners, as necessary, for initial start-up operation and for controlling the temperatures within the different chambers of the reactor to carry out the particular processing desired.

[0038] Depending on the feedstock, the multiple hearth vertical bed reactor 100 can be operated in at least two configurations, each one being characterized by a different waste organic material circulation path inside the reactor 100.

[0039] In a first and non-limitative implementation of Figure 2, the multiple hearth vertical bed reactor 100 is divided into a plurality of units, each one including an internal chamber 112, which are configured to be operated in parallel. Each one of the internal chambers 112 can have its respective housing inlet 114, housing outlet 118 and/or housing gas outlet 122, as shown. Therefore, a portion of waste organic material 12 is fed through the multiple hearth

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vertical bed reactor 100 into a respective one of the internal chambers 112 through its respective housing inlet 114. Thus, the plurality of internal chambers 112 are operated in parallel. For instance and without being limitative, this configuration/implementation can be used when the waste organic feed material 12 is comprised of solid particles such as waste biomass material, shredded waste rubber tires, and crumb rubber.

[0040] In a second and non-limitative implementation, the plurality of internal chambers of the multiple hearth vertical bed reactor 100 can be operated in series. This configuration/implementation can be used when the waste organic material 12 is comprised of a material converting into a liquid phase upon thermal decomposition, such as waste plastic material. In this implementation, the multiple hearth vertical bed reactor can include a single housing inlet, a single housing outlet as well as a single housing gas outlet, as shown in the non-limitative embodiment of Figure 3, and as described in more details below. For example, the single housing inlet can extend through the longitudinally-extending housing, in an upper portion thereof. Once fed into the longitudinally-extending housing, the waste organic material 12, such as waste plastic material, which can be converted in the molten state, and the produced carbon-based by-product material, can travel downwardly through the longitudinally-extending housing, from one supporting tray to an adjacent one of the supporting trays (i.e., from the uppermost supporting tray towards the lowermost supporting tray), and towards the housing outlet, which can extend through the longitudinally-extending housing, in a lower portion thereof. The waste plastic material can thus be fed into an upper one of the plurality of hearths first, so as to be supported and heated by an upper one of the plurality of supporting trays, and then, can travel downwardly into the longitudinally-extending housing from one hearth to another towards the lowermost supporting tray, as described in more details below. Still referring to the non-limitative embodiment of Figure 3, the single housing outlet can extend through the longitudinally extending housing, at a lower portion thereof. Similarly, since the plurality of internal chambers can be operated in series, the single housing gas outlet can extend through the longitudinally-extending housing, at the upper portion thereof. Hydrocarbons-containing gases, that naturally flow upwardly through the longitudinally-extending housing, from the lowermost hearth towards the uppermost hearth, can thus be discharged out of the uppermost hearth, towards the condensation system 300 for example.

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[0041] Even though the second and non-limitative implementation wherein the internal chambers are operated in series is described above as including a single housing inlet, a single housing outlet as well as a single housing gas outlet, it is appreciated that it can include more than one housing inlet, housing outlet, and housing gas outlet which are in matter communication so that the waste organic material 12 can flow downwardly from one supporting tray to an adjacent and lower one of the supporting trays. The solid residues are output through the housing outlet(s) located in the lower portion of the longitudinally-extending housing while the gaseous hydrocarbons exit the multiple hearth vertical bed reactor 100 through the housing gas outlet(s).

[0042] The residence time of the waste organic material 12 in the parallel configuration/operation mode is shorter than the residence time of the waste organic material 12 in the series configuration/operation mode. For instance, the residence time of waste biomass material processed in the multiple hearth vertical bed reactor 100 operated in parallel can range from about 10 minutes to about 30 minutes and, in a particular embodiment, about 15 minutes. For instance, the residence time of waste plastic material processed in the multiple hearth vertical bed reactor 100 operated in series can range from about 60 minutes to about 90 minutes and, in a particular embodiment, about 75 minutes.

[0043] Referring back to the non-limitative embodiments of Figures 2, 4 and 5, the multiple hearth vertical bed reactor 100 further includes a longitudinally-extending central rotatable shaft 142 which extends between shaft longitudinal ends 144, 145. The longitudinally-extending central rotatable shaft 142 extends axially through the longitudinally-extending housing 102 and is rotatably mounted to the longitudinally-extending housing 102 at the respective housing longitudinal ends 106, 108. For example, the longitudinally-extending central rotatable shaft 142 can be rotatably driven by a motor and gear drive, provided for that purpose. Each supporting tray 124 can define a shaft-receiving hole 128 which is shaped, sized and configurated so that the longitudinally-extending central rotatable shaft 142 can extend through the shaft-receiving holes 128 formed in the plurality of supporting trays 124. Where the multiple hearth vertical bed reactor 100 includes a single housing inlet 114 for admitting the waste organic material 12 into the uppermost internal chamber 112 or hearth 104, a single housing outlet 118 for discharging the carbon-based by-product material 16 out of the lowermost internal chamber 112 or hearth 104, as well as a single housing gas outlet 122 for discharging the produced oxygenated compounds-containing gases 18 out of

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the uppermost internal chamber 112 or hearth 104, holes (not shown) can extend through the plurality of supporting trays 124, for allowing passage of oxygenated compounds-containing gases 18 from the lowermost hearth 104 towards the uppermost hearth 104 and discharge of the oxygenated compounds-containing gases 18 out of the longitudinally-extending housing 102 through the housing gas outlet 122, as well as passage of the waste organic material 12 and/or of the carbon-based by-product material 16 from the uppermost hearth 104 towards the lowermost hearth 104, for discharge of the particles out of the longitudinally-extending housing 102 through the housing outlet 118. Such holes can be provided adjacent to the longitudinally-extending housing 102 of the multiple hearth vertical bed reactor 100, and/or adjacent to the longitudinally-extending central rotatable shaft 142. Indeed, according to the non-limitative embodiment of Figure 3, a bed of the waste organic particles 12 can be received onto the tray support surface 126 of the uppermost supporting tray 124. The bed of waste organic particles 12 can thus be transported from an upper supporting tray to a lower supporting tray 124 by means of a conveying and agitating system 140 (as described below), which can move the particles on each supporting tray 124 towards and into the discharging holes (not shown) formed in the supporting trays 124 so as to fall on a lower supporting tray 124. In one implementation, the supporting trays 124 can be heated at temperatures to provide a vertical temperature gradient between the uppermost and the lowermost supporting trays 124, with the lowermost tray being heated at a temperature higher than the uppermost tray. In another implementation, the temperature of the different supporting trays 124 remains constant throughout the reactor 100, as described below.

[0044] Now referring more particularly to the non-limitative embodiment of Figure 4, the multiple hearth vertical bed reactor 100 further includes a conveying and agitating system 140, disposed inside the longitudinally-extending housing 102, for mixing together the waste organic particles 12 and the produced carbon-based by-product particles 16 disposed on the tray support surfaces 126, and for displacing the produced carbon-based by-product particles 16 along predetermined directions (e.g., outwardly of the longitudinally-extending central rotatable shaft 142) on the tray support surfaces 126 and towards the plurality of corresponding housing outlets 118. The conveying and agitating system 140 includes a plurality of vertically spaced-apart rotating rake members 146 extending across the tray support surface 126. As best shown in the non-limitative embodiment of Figure 4, the plurality of rotating rake members 146 are secured to the longitudinally-extending rotatable

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center shaft and spaced-apart along a length thereof. Each rotating rake member 146 extends outwardly of the longitudinally-extending central rotatable shaft 142 in a respective one of the plurality of hearths 104 and above a respective one of the plurality of supporting trays 124. Each rotating rake member 146 includes longitudinally-extending arms 148 which extend outwardly of the longitudinally-extending central rotatable shaft 142, as well as a plurality of fingers 150, which extend downwardly from the plurality of longitudinally-extending arms 148 and towards a corresponding supporting tray 124. The fingers 150 are shaped, sized and configured so as to be in sliding contact with their corresponding tray support surface 126. Indeed, the fingers 150 are spaced-apart along the length of their respective longitudinally-extending arm 148 such that the fingers 150 can rake across substantially the entire tray support surface 126 of their respective supporting tray 124 and constantly stir the particles 12, 16 while displacing them. Fresh surfaces of the waste organic particles 12 to be pyrolyzed are thus constantly put into contact with the heated tray support surface 126 and with other hot carbon-based by-product particles 16, increasing heat transfer in the bed of the waste organic material 12.

[0045] Still referring to the non-limitative embodiment of Figure 4, each finger 150 includes a finger upper portion 152 secured to the longitudinally-extending arm 148, and a finger lower portion 154 which downwardly extends from the finger upper portion 152, at an angle thereof, so that as the rotating rake members 146 are carried around by the rotation of the longitudinally-extending central rotatable shaft 142, the fingers 150 can continuously rake through the waste organic particles being heated and/or the produced carbon-based by-product particles disposed on the corresponding lower supporting tray 124 and gradually urge the carbon-based by-product material 16 produced towards the plurality of housing outlets 118 which extend through the longitudinally-extending housing 102 (biomass material treated) or alternatively, through the single housing outlet 118 which extends through the longitudinally-extending housing 102, at the lower portion thereof (plastic material treated). It is noted that the conveying and agitating system 140 and, more particularly, the rotating rake members 146, can take any shape, size or configuration allowing the waste organic particles 12, the carbon-based by-product particles 16 or the combination thereof to be agitated and eventually discharged out of the longitudinally-extending housing 102. Each rotating rake member 146 can thus include more or less longitudinally-extending arms 148, and similarly, more or less fingers 150. The longitudinally-extending arms 148 and the fingers 150 can also take any shape, size or

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configuration allowing agitation of the waste organic particles 12 with the carbon-based by-product particles 16 and eventually, transport of the carbon-based by-product particles 16 out of the multiple hearth vertical bed reactor 100. The conveying and agitating system 140 produces a forced exchange between the feedstock particles 12 being heated via the tray support surfaces 126 of the supporting trays 124 and the colder feedstock particles 12 located at the core of the packed particle bed. Thus, and as mentioned above, the heat transfer between the multiple hearth vertical bed reactor 100 and the waste organic particles 12 is increased.

[0046] In operation, and still referring to the non-limitative embodiments of Figures 1 to 5, the waste organic material 12 can be fed through the longitudinally-extending housing 102 and heated, under vacuum, from ambient temperature to a reactor temperature of between about 250°C and about 500°C. A plurality of multiple hearth vertical bed reactors with different reactor temperatures can also be put in series, one adjacent to the other. To provide the required heat to the multiple hearth vertical bed reactor 100, and thus to the waste organic particles 12, heat carrier molten salts can be fed through the molten salt-receiving channels defined by the supporting trays 124. Heat exchange can thus occur between the heat carrier molten salt material and the supporting trays 124, and thus, between the supporting trays 124 and the waste organic particles 12 supported thereon. The hydrocarbons-containing gases (plastic feedstock) or oxygenated compounds-containing gases (biomass feedstock) 18 (i.e., the pyrolysis vapors) can rapidly be evacuated from the hot internal chambers 112 by means of a vacuum pump or blower for example, which can maintain a total pressure of between about 2 kPa and about 20 kPa in the internal chambers 112.

[0047] After the waste organic particles/carbon-based by-product particles 12, 16 have spent a residence time into the internal chambers 112, the solid carbon-based by-product residues 16 can leave the multiple hearth vertical bed reactor 100 under vacuum. For example, depending on the nature of the waste organic material, the particles 12 can remain in the internal chambers 112 for between about 10 minutes and about 100 minutes. For example, biomass particles can remain in the internal chambers between about 10 and about 20 minutes, while the plastic material, which can enter the reactor in a semi-molten state, can remain in the internal chambers between about 75 and about 100 minutes. For example, the residence time can be of about 15 minutes when waste biomass material is

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fed through the reactor, or of about 75 minutes when waste plastic particles are fed through the reactor. For example, residence time of the particles into the reactor can depend on the nature of the particles to be heat treated. The obtained hot carbon-based by-product particles 16 can be cooled, for example, with water or alternatively, can remain in a container, without being cooled, to promote additional heat transfer between the particles contained in the container. On the other hand, the hydrocarbons-containing gases 18 (where plastic material is fed through the reactor) can be condensed in a condensation system 300, as described in more details below.

[0048] Still referring to the non-limitative embodiment of Figure 1, and as mentioned above, the system 10 further includes a reactor heating system 200 for heating the heat carrier molten salt material 20 so as to increase the temperature of the plurality of supporting trays 124, and thus, of the waste organic material 12 supported thereon, to the reactor temperature. The reactor heating system 200 can include a container 202 for containing the heat carrier molten salt material therein, as well as a molten salt heating device 204, a furnace for example, in communication with the container 202, for heating the heat carrier molten salts being introduced therein. It is noted that the thermal salt material can be fed through the molten salt heating device 204 using a conventional pump. The molten salt heating device 204 has a heating device housing 206 defining a molten salt containing chamber 208 and includes an inlet 210 which extends therethrough for receiving the heat carrier molten salt material (e.g., fresh thermal salts) from the container 202, an inlet 212 extending through the heating device housing 206 for receiving the heat carrier molten salt material from the plurality of supporting trays 124 of the multiple hearth vertical bed reactor 100 (i.e., the heat carrier molten salts that have transferred their heat to the waste organic material 12), as well as an outlet 214 extending through the heating device housing 206 for discharging the heat carrier molten salts out of the heating device housing 206 and towards the supporting trays 124 of the multiple hearth vertical bed reactor 100. The molten salt heating device 204 can thus be in fluid communication with the longitudinally-extending housing 102 of the multiple hearth vertical bed reactor 100 and more particularly, with the supporting trays 124, allowing flow of the heat carrier molten salts therethrough.

[0049] The heat carrier molten salt material is solid at standard temperature and pressure, but enters the liquid phase when subjected to an elevated temperature (i.e., the reactor temperature). The heat carrier molten salts are thus used as a heat transfer fluid. For

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example, the heat carrier molten salt material can be the eutectic mixture of sodium nitrate and potassium nitrate, which can be used as liquid between about 150°C and about 550°C. Below 150°C lies the melting point of the mixture (at about 142°C) and above 550°C, the salt will degrade too rapidly. For example, at about 500°C, the heat carrier molten salts can have a specific heat capacity of about 1549 J/[kg.°K] and a thermal conductivity of about 0.61 W/[m°K].

[0050] Thus, in operation, the heat carrier molten salt material (e.g., Hitec®) can flow through the molten salt-receiving channels of the supporting trays 124 for indirectly heating the waste organic particles 12 which are conveyed on the tray support surfaces 126 by the conveying and agitating system 140 (i.e., by the plurality of rotating rake members 146). For example, the heat carrier molten salts can be discharged from the molten salt heating device 204 at an initial temperature of between about 450 and 485°C and discharged from the molten salt-receiving channels formed in the supporting trays 124 at a final temperature of between about 445°C and about 455°C.

[0051] The heat carrier molten salts leaving the multiple hearth vertical bed reactor 100 can be collected in the container 202 which can be equipped with a pump to circulate the cooled molten thermal salts through the reactor heating system 200 to be reheated and then back to the multiple hearth vertical bed reactor 100.

[0052] The direct contact of the waste organic particles 12 with the tray support surfaces 126 of the supporting trays 124 (i.e., the heated surfaces) allows both conduction and radiation heat transfer, which increases the overall heat transfer coefficient of the multiple hearth vertical bed reactor 100. Indeed, the heat transfer coefficient of the multiple hearth vertical bed reactor 100 can be as high as between about 200 and about 1000 W/[m².°K], depending on the size and nature of the waste organic particles.

[0053] The thermal decomposition process which can occur into the multiple hearth vertical bed reactor 100 can enable a large variety of solid and semi-liquid wastes to be transformed into useful products, including the hydrocarbons-containing gases or oxygenated compounds-containing gases 18.

Condensation system

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[0054] Now referring to the non-limitative embodiment of Figure 1, and as mentioned above, the system 10 further includes a condensation system, or cyclic condensation system 300, for treating the hydrocarbons-containing gases 18 resulting from a pyrolytic or thermal decomposition of a waste organic material 12 which comprises a polymer or a mixture of polymers, so as to recover one or more hydrocarbon(s) contained in the hydrocarbons-containing gases 18 for further purification. Indeed, the system 10 can be used to perform the pyrolysis of plastic compounds, where some of these plastic compounds can be contaminated for example, with organic (e.g., food, labels, etc.) and/or inorganic (e.g., glass, earth, etc.) materials. Thus, before they can be used, the hydrocarbons-containing gases 18 resulting from the thermal decomposition reaction, must be condensed and freed from undesirable compounds.

[0055] A condensation system 300, collecting the hydrocarbons-containing gases 18 from the multiple hearth vertical bed, can be used to both cool and separate certain compounds. A non-limitative embodiment of a condensation system 300 is described in more details below. The condensation system 300 can be used to cool and recover certain hydrocarbons, which can subsequently be purified and upgraded. This approach based on condensation is unknown in the field of pyrolysis.

[0056] The condensation system 300 can include a condensation unit which can be configured to be operated at a pressure P1. The condensation unit can include a condensation vessel, a gas inlet which can extend through the condensation vessel for admitting the hydrocarbons-containing gases 18 therein, a liquid outlet which can extend through the condensation vessel, at a lower portion thereof, for discharging a condensed polymer-containing material therefrom, as well as a gas outlet which can extend through the condensation vessel, at an upper portion thereof, for discharging the remaining non-condensable gases therefrom.

[0057] The condensation unit can also be equipped with an absorption device. The absorption device can be configured so as to inject an absorbent liquid into the condensation vessel, allowing contact between the absorbent liquid and the hydrocarbons-containing gases 18. For example, the absorption device can be a liquid dispersion device, a packed column, a dispersion system, etc. Since, the temperature of the absorbent liquid is lower than the temperature of the hydrocarbons-containing gases 18, the hydrocarbon(s)

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contained in the hydrocarbons-containing gases 18 can condense in the absorbent liquid by heat exchange. For example, cooling in the condensation vessel of the condensation unit can be carried out using a counter-current approach or alternatively, a co-current approach.

[0058] In operation, the absorbent liquid, water for example, can be injected into the condensation unit, for contacting with the hydrocarbons-containing gases 18 discharged from the multiple hearth vertical bed reactor 100. Since the temperature of the absorbent liquid is lower than the temperature of the hydrocarbons-containing gases 18, the hydrocarbons contained in the hydrocarbons-containing gases 18 can therefore condense in the absorbent liquid by heat exchange.

[0059] The condensed hydrocarbons-containing liquid 22 (Figure 1) having the first pressure P1, and which contains in particular the hydrocarbons(s) and the absorbent liquid, also called condensate, can be discharged via the liquid outlet, preferably located at the bottom of the condensation vessel. In an alternative embodiment, when the condensate is in the form of a two-phase system, the system 10 can also include a separation device 360 (Figure 1) for separating the compounds by filtration, decantation or centrifugation, for example. According to this embodiment, a first phase of absorbent liquid, essentially depleted of the hydrocarbons(s) that have condensed, can be reinjected, via a pump, into the condensation unit, via the absorption device. On the other hand, a second phase can be subjected to a partial vaporization unit. The separation device 360 can thus allow a first purification of the condensate. The separation device 360 can therefore be arranged upstream of the partial vaporization unit. For example, the separation device 360 can be a filter, a decanter, and/or a centrifuge.

[0060] During the condensation stage, a light molar fraction (i.e., non-condensable gases 24) contained in the hydrocarbons-containing gases 18 resulting from the pyrolysis of waste plastic material 12, may not be fully condensed by contact with the absorbent liquid. The non-condensable gases 24 can thus be evacuated out of the condensation unit, after a filtering step 370 when deemed required, in the gaseous state, via the gas outlet arranged at the upper portion of the condensation vessel. It is noted that the non-condensable gases 24 can be used to heat the molten salt heating device 204 via an indirect contact heat exchange, increasing the overall yield of the system 10.

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[0061] For example, the condensation unit can be maintained at a total pressure P1 of between about 10 and about 60 kPa. Moreover, the temperature of the absorbent liquid can be maintained at a temperature of between about 50 and about 95 °C.

[0062] Indeed, in accordance with a non-limitative embodiment, the partial vaporization unit can include a partial vaporization vessel, a liquid inlet which can extend through the partial vaporization vessel for admitting the condensed hydrocarbons-containing liquid 22 therein, a gas outlet which can extend through the partial vaporization vessel for discharging purified hydrocarbon-containing gases 26 (Figure 1) resulting from the partial vaporization, as well as a liquid outlet which can extend through the partial vaporization vessel for discharging the non-vaporized liquid 28.

[0063] The purified hydrocarbon-containing gases 26 can then be sent to a heat exchanger in order to be condensed, and to the distillation column, in order to be separated in different fractions. Indeed, the fraction rich in hydrocarbons can thus be upgraded so as to produce the petroleum product, biooils, etc. When the non-vaporized liquid 28 contains an important proportion of the absorbent liquid, it can in turn be redirected, at least in part, to the condensation unit, where it will again be able to absorb the hydrocarbon(s) by heat exchange. The absorbent liquid therefore circulates in a closed loop in the condensation system 300, and can be transported by a pump, for example.

[0064] The partial vaporization unit, towards which can be conveyed the condensed hydrocarbons-containing liquid 22, can be configured to be maintained at a second pressure P2 being lower than the first pressure P1, as mentioned above. The condensate 22 being subjected to the partial vaporization unit can then be expanded, which can cause partial adiabatic vaporization of the condensate 22.

[0065] It is noted that, depending on the hydrocarbon(s)/absorbent liquid combination being selected, the hydrocarbons, resulting from the decomposition of the plastic residues, will be mostly contained in the vapor fraction (i.e., the purified hydrocarbons-containing gases 26). Indeed, if the absorbent liquid is chosen so that its boiling point is higher than the boiling point of the hydrocarbon(s) to be recovered, then the hydrocarbon(s) will be mostly contained in the vapor fraction (i.e., the purified hydrocarbons-containing gases 26). Advantageously, the purified hydrocarbons-containing gases 26 comprises the hydrocarbons. The purified hydrocarbons-containing gases 26 can then be conveyed to a

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heat exchanger in order to be condensed, and then to a purification device 380, such as a distillation column for example, in order to be purified. This fraction rich in hydrocarbons can then be upgraded. The condensation system 300 therefore makes it possible to treat the hydrocarbons-containing gases 18 resulting from the pyrolytic decomposition of a polymer or a mixture of polymers, in order to be able to recover a product of interest contained in these gaseous effluents.

[0066] It is also noted that the condensation system 300 can include a purge configured for discharging the absorbent liquid from the cyclic condensation system 300, and an injection device configured for reinjecting the absorbent liquid in the cyclic condensation system 300, so as to make sure that the absorbent liquid is not saturated with impurities and can still absorb the hydrocarbons to be recovered. In addition, the condensation system 300 can further include an intermediate heat exchanger (not shown) disposed between the liquid outlet of the partial vaporization unit and the absorption device of the condensation unit. Such heat exchanger can further cool the non-vaporized liquid 28 discharged from the partial vaporization unit.

[0067] The absorbent liquid can be selected so as to optimize heat exchange between the hydrocarbons-containing gases 18 and the liquid absorbent in the condensation unit, and also partial vaporization of the condensate (i.e., the condensed polymer-containing liquid 22) during expansion in the partial vaporization unit. The nature of the selected absorbent liquid therefore depends on the hydrocarbon(s) that is/are to be recovered.

[0068] Although the present invention has been described hereinabove by way of specific embodiments thereof, it can be modified, without departing from the spirit and nature of the subject invention defined in the appended claims.

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CLAIMS:

1. A multiple hearth vertical bed reactor for pyrolyzing a waste organic material to obtain a carbon-based by-product material and hydrocarbons-containing gases or oxygenated compounds-containing gases, the multiple hearth vertical bed reactor comprising:

a longitudinally-extending housing defining a plurality of internal chambers and a housing longitudinal axis;

at least one housing inlet extending through the longitudinally-extending housing for admitting the waste organic material into the plurality of internal chambers;

at least one housing outlet extending through the longitudinally-extending housing for discharging the carbon-based by-product material resulting from a pyrolysis reaction out of the plurality of internal chambers;

at least one housing gas outlet extending through the longitudinally-extending housing, at an upper portion thereof, for discharging the hydrocarbons-containing gases or oxygenated compounds-containing gases resulting from the pyrolysis reaction out of the plurality of internal chambers;

a plurality of supporting trays disposed horizontally inside the longitudinally-extending housing and spaced-apart along the housing longitudinal axis for supporting and heating the waste organic material to a temperature that allows the pyrolysis reaction to occur, to produce the carbon-based by-product material and the hydrocarbons-containing gases or oxygenated compounds-containing gases, each supporting tray defining:

a tray support surface for supporting the waste organic material and the produced carbon-based by-product material thereon; and

a molten salt-receiving channel having a channel inlet and a channel outlet, the molten salt-receiving channel being configured to allow flow of a heat carrier molten salt material, capable of heat transfer to the tray support surface, therethrough and between the channel inlet and the channel outlet; and

a conveying and agitating system disposed inside the longitudinally-extending housing for mixing together the waste organic material and the produced carbon-based by-product material on the tray support surfaces and for displacing the

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produced carbon-based by-product material along a predetermined direction on the tray support surfaces and towards the at least one housing outlet.

2. A condensation system for treating hydrocarbons-containing gases resulting from a pyrolytic decomposition of a waste organic material comprising at least one polymer to recover at least one hydrocarbon contained in the hydrocarbons-containing gases, the system comprising:

a condensation unit configured to be maintained under a first pressure P1, the condensation unit comprising:

a condensation vessel;

a gas inlet extending through the condensation vessel for admitting therein the hydrocarbons-containing gases;

an absorption device disposed within the condensation vessel and configured to allow contact of the hydrocarbons-containing gases with an absorbent liquid having a temperature being lower than the temperature of the hydrocarbons-containing gases to obtain a condensed hydrocarbons-containing liquid and non-condensable gases;

a liquid outlet extending through the condensation vessel, at a lower portion thereof, for discharging the condensed hydrocarbons-containing liquid; and

a gas outlet extending through the condensation vessel, at an upper portion thereof, for discharging the non-condensable gases;

a partial vaporization unit in fluid communication with the condensation unit configured to be maintained under a second pressure P2 lower than the first pressure P1 so as to trigger expansion of the condensed hydrocarbons-containing liquid and its partial adiabatic vaporization to produce purified hydrocarbons-

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containing gases and a non-vaporized liquid, the partial vaporization unit comprising:

a partial vaporization vessel;

a liquid inlet extending through the partial vaporization vessel for admitting therein the condensed hydrocarbons-containing liquid;

a gas outlet extending through the partial vaporization vessel, at an upper portion, for discharging the purified hydrocarbons-containing gases; and

a liquid outlet extending through the partial vaporization vessel, at a lower portion thereof, for discharging the non-vaporized liquid; and

a pump in fluid communication with both the condensation unit and the partial vaporization unit and configured to recirculate the non-vaporized liquid from the partial vaporization unit into the condensation unit through the absorption device.

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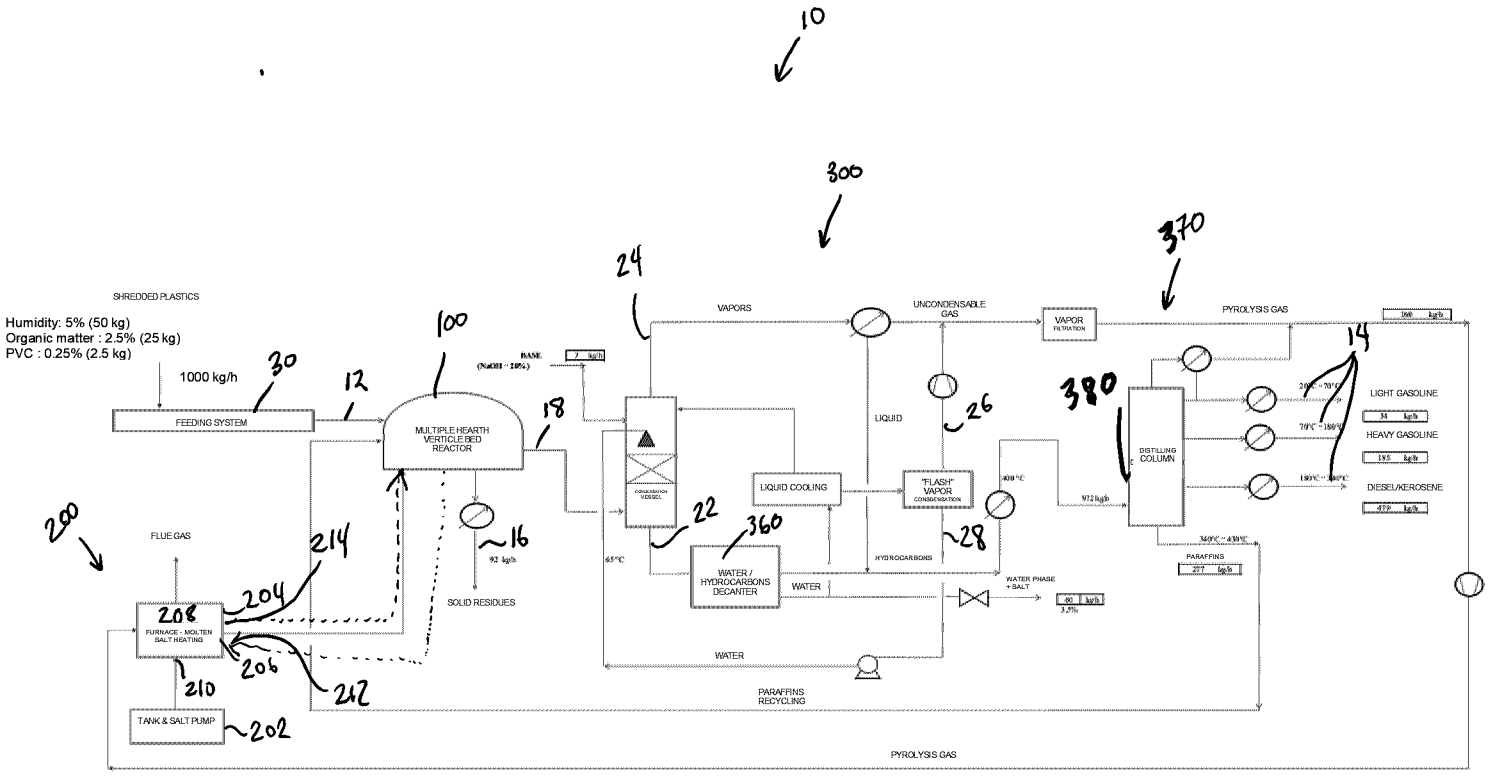


Figure 1

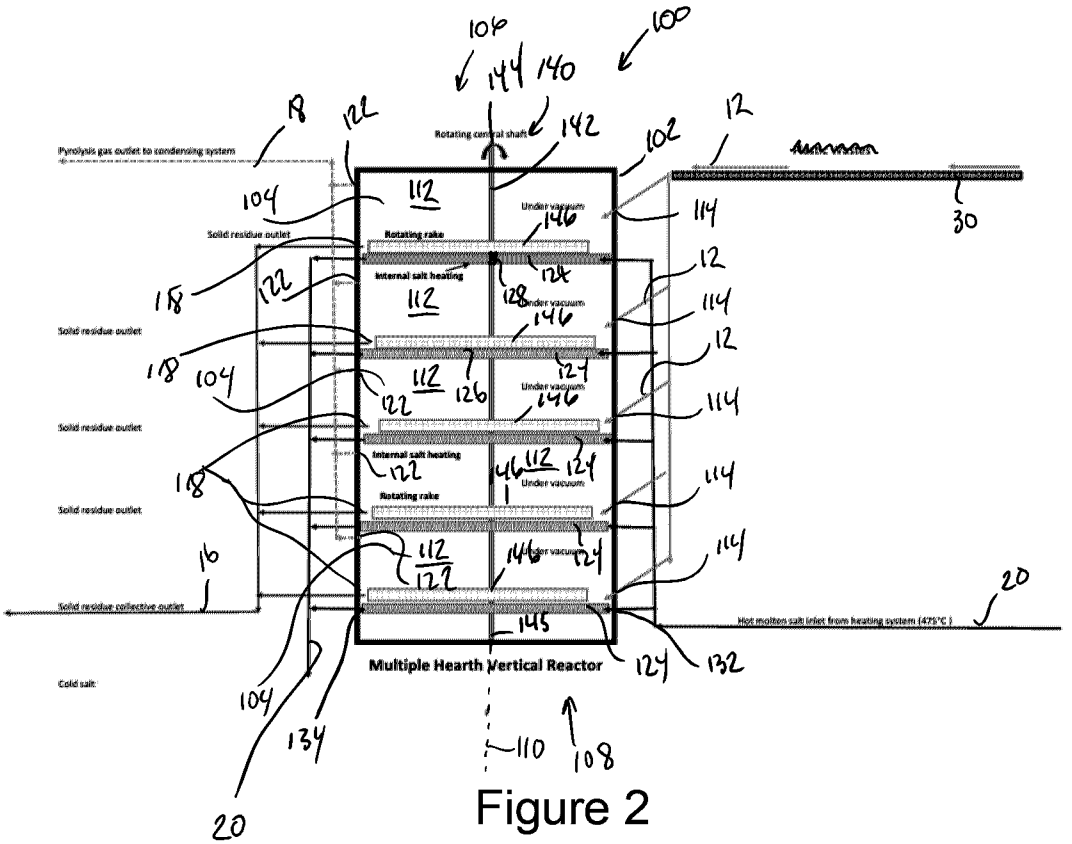


Figure 2

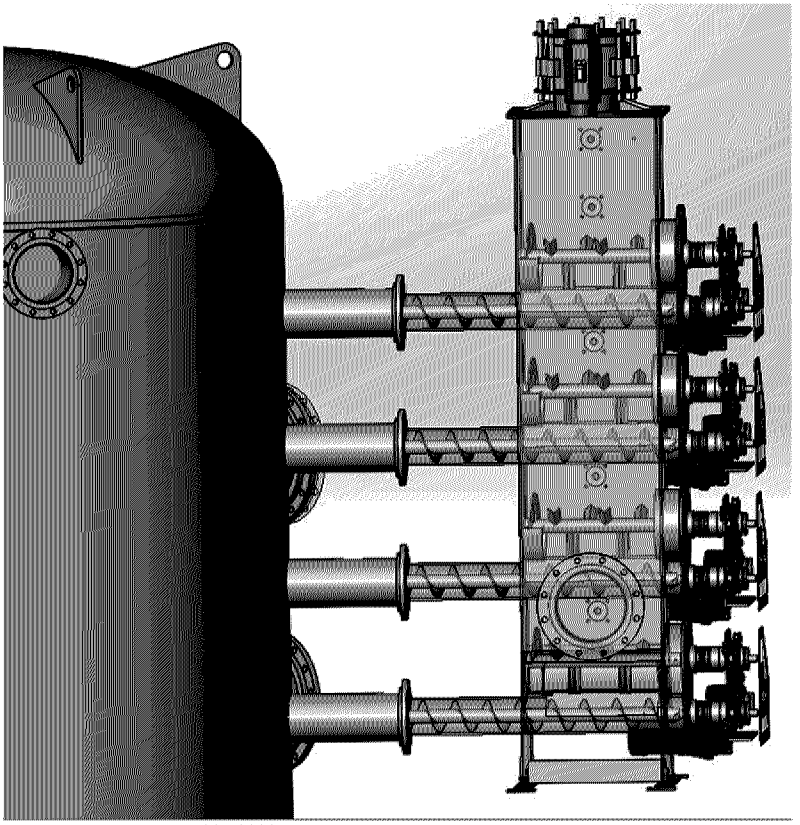


Figure 3

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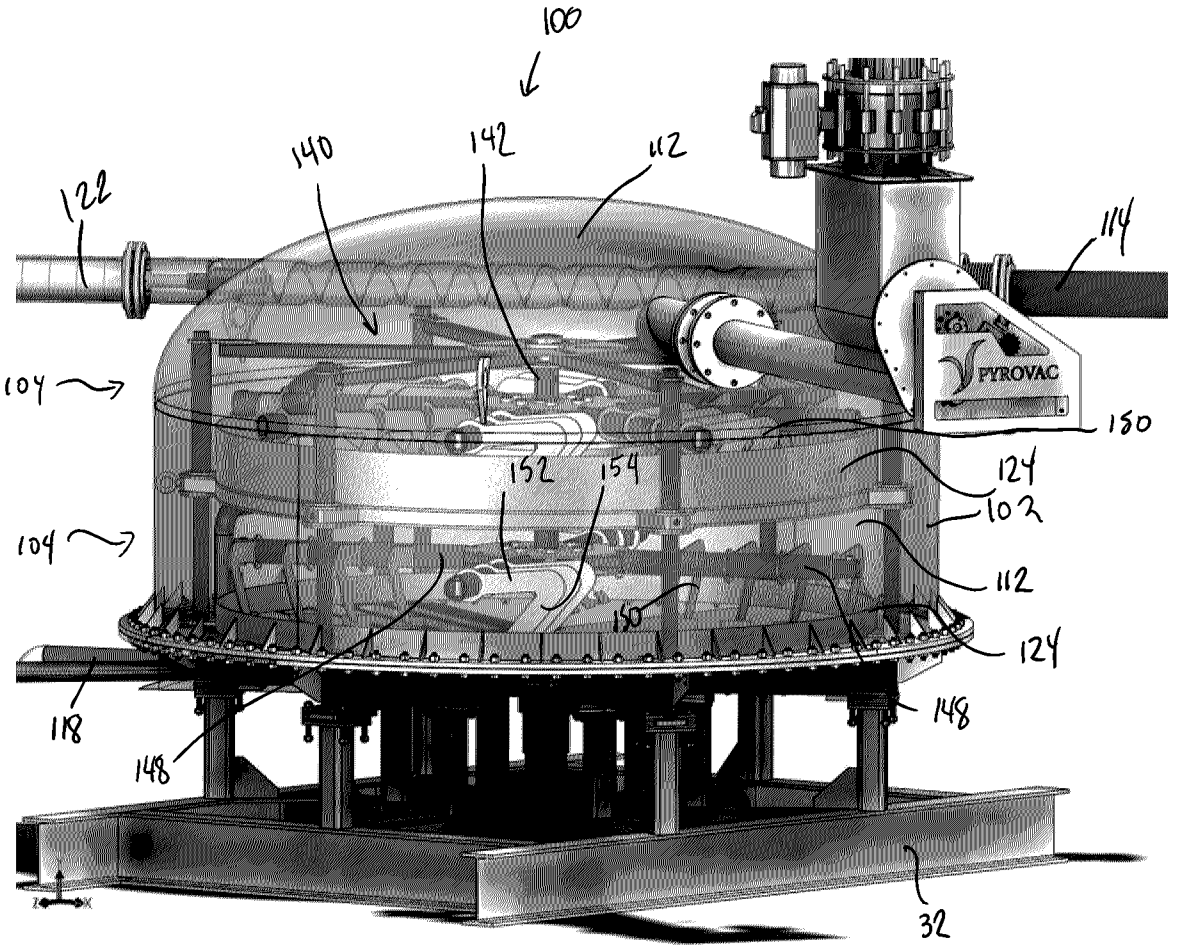


Figure 4

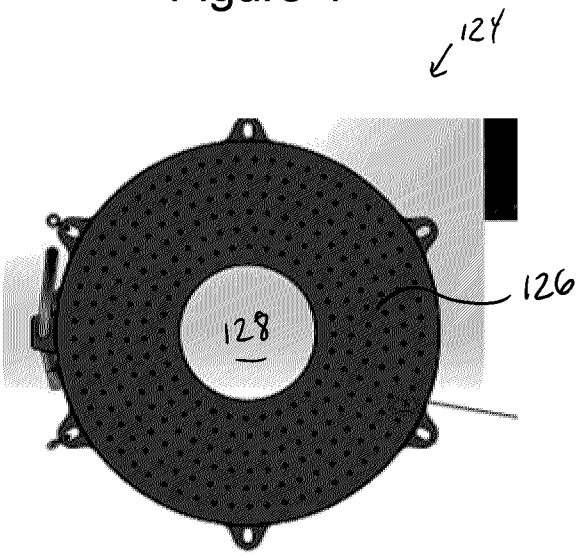
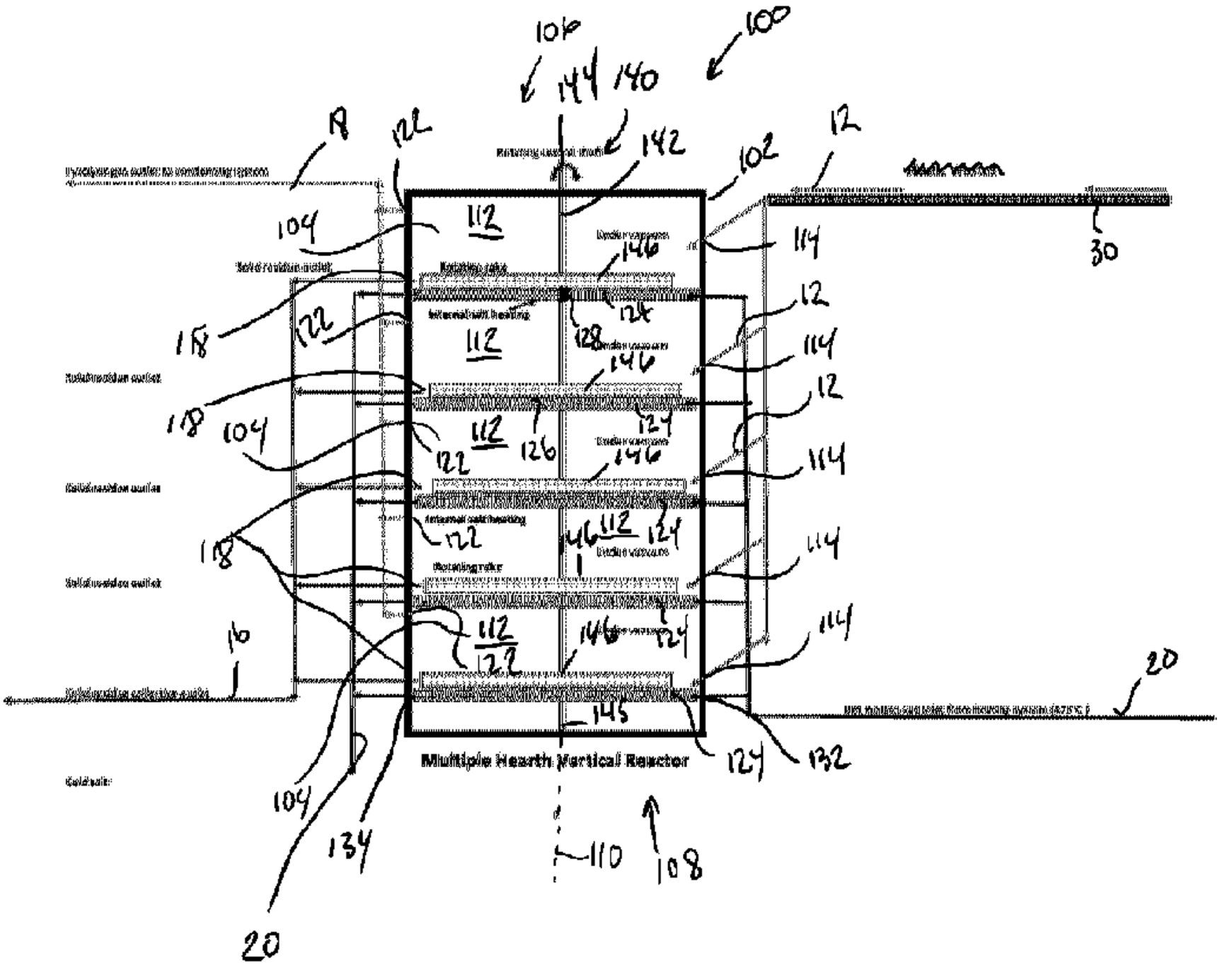


Figure 5

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Multiple Hearth Vertical Reactor