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- (54) Title: PYROLYSIS OR GASIFICATION LOOP USING AN AUGER

(57) Abstract: Systems and apparatuses are provided for pyrolyzing and gasifying a biomass material.

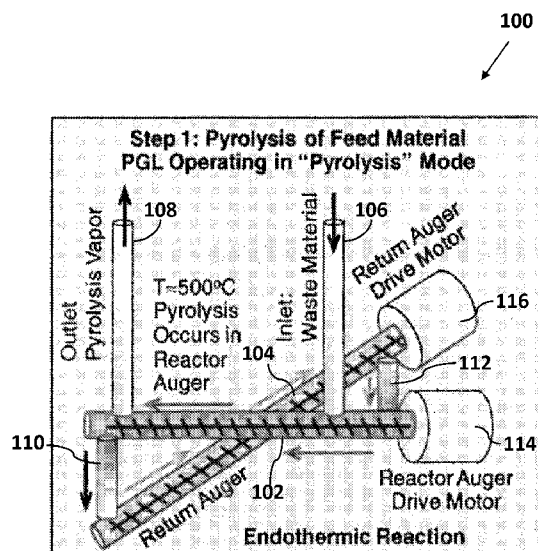


FIG. 1



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PYROLYSIS OR GASIFICATION LOOP USING AN AUGER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from U.S. Provisional Patent Application No. 61/801,147, filed on March 15, 2013, which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] The extraction of bio oil from biomass for use as a biofuel is an area of interest in the search for reliable alternative energy sources. Biomass may be subjected to pyrolysis to create a hot pyrolysis vapor. Bio oil may be extracted from the hot pyrolysis vapor. Additionally, biomass may be subjected to gasification to create a syn gas.

[0003] Systems and apparatuses are needed for the pyrolysis and gasification of biomass.

SUMMARY

[0004] In one embodiment, a single pyrolysis gasification loop for pyrolyzing a biomass material is provided, the single pyrolysis gasification loop comprising: a reactor auger operatively connected to at least one of a biomass inlet and a vapor outlet; and a return auger; wherein the reactor auger and the return auger are operatively connected by at least one of a reactor outlet and a return outlet; wherein the reactor auger is operable to advance the biomass material to the return auger via the reactor outlet; wherein the return auger is operable to advance the biomass material to the reactor auger via the return outlet; and wherein the reactor auger is operable to pyrolyze the biomass material.

[0005] In another embodiment, a single pyrolysis gasification loop for gasifying a char material is provided, the single pyrolysis gasification loop comprising: a reactor auger operatively connected to at least one of a heat inlet and a gas outlet; and a return auger; wherein the reactor auger and the return auger are operatively connected by at least one of a

reactor outlet and a return outlet; wherein the reactor auger is operable to advance the char material to the return auger via the reactor outlet; wherein the return auger is operable to advance the char material to the reactor auger via the return outlet; and wherein the reactor auger is operable to gasify the char material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The accompanying figures, which are incorporated in and constitute a part of the specification, illustrate example systems and apparatuses, and are used merely to illustrate example embodiments.

[0007] **FIG. 1** illustrates an example arrangement of a single pyrolysis gasification loop (“PGL”) operating in a pyrolysis mode.

[0008] **FIG. 2** illustrates an example arrangement of a single PGL operating in a gasification mode.

DETAILED DESCRIPTION

[0009] The processing of biomass to extract bio oil therefrom may involve the pyrolysis of biomass to create a hot pyrolysis vapor. Pyrolysis processes may include fast pyrolysis of biomass material at temperatures of about 500 °C. When biomass undergoes pyrolysis, three groups of components may be created, including: non-condensable gases, vapor that may be quenched into bio oil, and solids known as char and coke.

[0010] Char and coke may be gasified utilizing a gasification process to generate a produce, such as a syn gas product, and energy in the form of heat.

[0011] **FIG. 1** illustrates an example arrangement of a PGL **100** operating in a pyrolysis mode. PGL **100** may comprise a series of augers, including a reactor auger **102** and a return auger **104**. PGL **100** may be configured to intake biomass material via a biomass inlet **106**.

PGL **100** may be configured to outlet a pyrolysis vapor via a vapor outlet **108**. Biomass inlet **106** may be operatively connected to at least one of reactor auger **102** and return auger **104**. Vapor outlet **108** may be operatively connected to at least one of reactor auger **102** and return auger **104**.

[0012] PGL **100** may comprise a 1-3 ton waste to energy conversion (“WEC”) system comprising two separate modules. A first module may be configured for feed pretreatment (such as sizing) and/or thermochemical conversion, while a second module may be configured for production of fuels and/or electric power. Each of the first module and the second module may be configured to fit in containers having dimensions of about 8 ft. by about 8 ft. by about 20 ft. PGL **100** may be configured to fit entirely in a container having dimensions of about 8 ft. by about 8 ft. by about 20 ft. PGL **100** may be configured to fit entirely in a container having dimensions less than about 8 ft. by about 8 ft. by about 20 ft. PGL **100** may be operatively connected to upstream and downstream components, such as dryers, size attrition devices, and electrical generator sets.

[0013] In one embodiment, PGL **100** is configured to be very compact. PGL **100** may not require fluidization gas. PGL **100** may not require the associated auxiliary equipment required for conventional thermochemical conversion technologies. PGL **100** may not require a separate continuous heating system. PGL **100** may include minimal parasitic loss. PGL **100** may include thermal storage and temperature control via phase change media. PGL **100** may exceed 50% net energy recovery. PGL **100** may be configured to simultaneously produce both a low oxygen bio oil and a syn gas.

[0014] The low oxygen bio oil generated by PGL **100** may be a stable product. The low oxygen bio oil may be stored for later use. The low oxygen bio oil may be used in a modified

diesel engine. The low oxygen bio oil may be converted to a hydrocarbon fuel that can be used by a vehicle.

[0015] The syn gas generated by PGL 100 may be used to produce electricity during operation of PGL 100. The syn gas may be utilized in an electrical generation system.

[0016] The biomass material may comprise any of a variety of lignocellulosic feed materials. The biomass material may comprise a wood or plant material. The biomass material may comprise waste.

[0017] PGL 100 may operate in parallel with additional PGL systems. A plurality of PGL systems, including PGL 100 may be oriented inside an insulated container. A plurality of PGL systems, including PGL 100, may be oriented with a phase change material in an insulated container. A plurality of PGL systems, including PGL 100 may be substantially surrounded by a phase change material in an insulated container. A plurality of PGL systems, including PGL 100 may be oriented with a phase change material in an insulated container, wherein at least one of reactor auger 102 and return auger 104 may be substantially surrounded by a phase change material.

[0018] Biomass may be introduced to PGL 100 via biomass inlet 106. Biomass may first be introduced into reactor auger 102. Reactor auger 102 may comprise an auger device within a substantially cylindrical housing. The auger device may be configured to advance material longitudinally along the interior of the substantially cylindrical housing. Biomass may be pyrolyzed within the cylindrical housing of reactor auger 102. Biomass may be exposed to temperatures of about 500 °C within reactor auger 102. Reactor auger 102 may contain granular heating media. Biomass may be contacted with granular heating media within reactor auger 102. Biomass may be pyrolyzed by contact with granular heating media within reactor auger 102.

[0019] Biomass within reactor auger **102** may undergo flash pyrolysis creating at least one of a vapor and a char (e.g., a fixed carbon). The vapor may exit PGL **100** via vapor outlet **108**. The char may exit reactor auger **102** via a reactor outlet **110**. Reactor outlet **110** may be operatively connected to return auger **104**. Reactor outlet **110** may be configured to transfer char from reactor auger **102** to return auger **104**. Char may be transferred from reactor auger **102** to return auger **104** along with granular heating media. Char may be mixed with granular heating media and transferred from reactor auger **102** to return auger **104**.

[0020] Return auger **104** may comprise an auger device within a substantially cylindrical housing. The auger device may be configured to advance material longitudinally along the interior of the substantially cylindrical housing. Material advancing through return auger **104** may be returned to reactor auger **102** via a return outlet **112**. Return outlet **112** may be operatively connected to reactor auger **102**. Return outlet **112** may be configured to transfer material, including char or granular heating media, from return auger **104** to reactor auger **102**.

[0021] In one embodiment, PGL **100** comprises reactor auger **102** and return auger **104** oriented in a continuous loop. The continuous loop may be formed by at least reactor auger **102**, reactor outlet **110**, return auger **104**, and return outlet **112**. Reactor auger **102** and return auger **104** may comprise heating media, including granular heating media.

[0022] In one embodiment, reactor auger **102** is operatively connected to a reactor motor **114**. Reactor motor **114** may comprise any motor capable of causing the auger device within reactor auger **102** to rotate. Reactor motor **114** may be configured to cause the auger device within reactor auger **102** to rotate at any of a variety of rotational velocities. Reactor motor **114** may be a stepper motor configured to cause the auger device within reactor auger **102** to rotate in a number of equal steps.

[0023] In one embodiment, return auger **104** is operatively connected to a return motor **116**. Return motor **116** may comprise any motor capable of causing the auger device within return auger **104** to rotate. Return motor **116** may be configured to cause the auger device within return auger **104** to rotate at any of a variety of rotational velocities. Return motor **116** may be a stepper motor configured to cause the auger device within return auger **104** to rotate in a number of equal steps.

[0024] PGL **100** may operate for a fixed time period of operation in pyrolysis mode, after which PGL operation may be switched to gasification mode (illustrated in **FIG. 2**). PGL **100** may operate for any of a variety of desired time periods, including a period of time on the order of minutes. A user may establish and adjust the time period of operation of the PGL system in pyrolysis mode or gasification mode.

[0025] **FIG. 2** illustrates an example arrangement of a PGL **200** operating in a gasification mode. PGL **200** may comprise a series of augers, including reactor auger **102** and return auger **104**. Reactor auger **102** may be operatively connected to reactor motor **114**, while return auger **104** may be operatively connected to return motor **116**. Reactor auger **102** and return auger **104** may be operatively connected by reactor outlet **110** and return outlet **112**.

[0026] PGL **200** may be configured to intake steam or heated air via a heat inlet **206**. PGL **200** may be configured to outlet a gas, such as syn gas, via a gas outlet **208**. In one embodiment, PGL **200** gasifies a char or coke in reactor auger **102**. Reactor auger **102** may comprise a temperature greater than about 500 °C. In another embodiment, reactor auger **102** comprises a temperature greater than about 660 °C. Gasification of a char or coke in reactor auger **102** may yield a syn gas, which may exit PGL **200** via gas outlet **208**. Heat inlet **206** may be operatively connected to at least one of reactor auger **102** and return auger **104**. Gas

outlet **208** may be operatively connected to at least one of reactor auger **102** and return auger **104**.

[0027] In one embodiment, PGL **200** comprises the same system and components as PGL **100**. In another embodiment, PGL **200** comprises a wholly separate system from PGL **100**. PGL **200** may comprise the same system and components as PGL **100**, with the exception of the addition of heat inlet **206** and gas outlet **208**.

[0028] In one embodiment, PGL **200** comprises the same system and components as PGL **100**, wherein biomass entering PGL **100** via biomass inlet **106** is replaced with hot air or steam entering PGL **200** via heat inlet **206**. Biomass inlet **106** and heat inlet **206** may be the same inlet tasked for different purposes when the PGL is operating in different modes. PGL **200** may comprise the same system and components as PGL **100**, wherein vapor exiting PGL **100** via vapor outlet **108** is replaced with syn gas exiting PGL **200** via gas outlet **208**. Vapor outlet **108** and gas outlet **208** may be the same outlet tasked for different purposes when the PGL is operating in different modes.

[0029] PGL **200** may be configured to gasify char and coke. The char or coke may be left over from pyrolysis performed in PGL **100**. PGL **200** may be configured to gasify and partially combust char or coke. PGL **200** may be configured to generate a gas, such as syn gas, from the gasification of char. PGL **200** may gasify at least a portion of the char or coke and leave noncombustible ash. The noncombustible ash may exit PGL **200** via gas outlet **208** with a gas.

[0030] PGL **200** may be configured to generate energy in the form of heat from the gasification of char. The energy generated by PGL **200** may be sufficient to provide at least a portion of the process heat and at least partially maintain the necessary reaction temperature in PGL **100** during pyrolysis, and/or in PGL **200** during gasification.

[0031] In one embodiment, a plurality of PGL systems are configured to operate simultaneously, with some operating in pyrolysis mode (e.g., PGL **100**) and others operating in gasification mode (e.g., PGL **200**). A plurality of PGL systems may be oriented within a container and thermally coupled via phase change media. A plurality of PGL systems may be operatively connected and share headers for biomass feed, heated air, syn gas, and pyrolysis vapor. The headers may comprise dampers configured to control the flow of biomass feed, heated air, syn gas, and pyrolysis vapor. The dampers may be controlled by at least one computer.

[0032] In one embodiment, switching between pyrolysis mode (e.g., PGL **100**) and gasification mode (e.g., PGL **200**) includes the use of dampers. The operation of PGL **100** and gasification **200** may include the use of dampers. The dampers may be controlled by a computer. The dampers may be configured to manage desired reactor temperature.

[0033] Phase change media may be selected, and thermal coupling between the PGL systems (e.g., PGL **100** or PGL **200**) may be designed, such that the absorption and release of the latent heat of fusion is at an appropriate temperature. Phase change media may be selected, and thermal coupling between the PGL systems (e.g., PGL **100** and PGL **200**) may be designed, such that sufficient temperature gradients are allowed in the solid and liquid phase of phase change media so that the PGL systems operate at the required temperatures in the pyrolysis mode (e.g., PGL **100**) and the gasification mode (e.g., PGL **200**). If more energy than necessary is generated by PGL **200** (gasification mode), phase change media may melt and an excessive temperature increase within PGL **200** may be prevented. If less energy than is sufficient is generated in PGL **100** (pyrolysis mode), phase change media may solidify, providing the necessary heat for PGL **100**. Phase change media may comprise a metal, such as aluminum. Phase change media may comprise a binary metal, such as Al-Cu. Phase change media may comprise binary salts, such as nitrate salts (e.g., NaNO₃-KNO₃)

with a temperature range between about 220 °C and about 540 °C. A control system (not shown) may monitor temperatures of the PGL systems to determine the mode of operation of individual PGL systems. A control system (not shown) may monitor any of various process parameters of the PGL systems to determine the mode of operation of individual PGL systems.

[0034] Granular heating media may comprise an inert substance. Granular heating media may comprise sand. Granular heating media may comprise an acidic catalyst. Granular heating media may comprise zeolites (e.g., HZSM-5, H-Beta, H-Mordenite, or the like). Granular heating media may comprise metal oxides (e.g., ZrO₂, TiO₂, CaO, ZnO, Dolomite, or the like). Granular heating media may comprise FCC catalysts, including spent FCC catalysts. Catalysts may be used during pyrolysis for effectively converting carboxylic acids to ketones, deoxygenating reactive compounds such as aldehydes and ketones, or depolymerizing heavy components. Catalysts may also be used during pyrolysis for effective depolymerization of pyrolysis vapor with relatively modest increase in reaction temperature.

[0035] Selection of the catalyst used as heating media, as well as selection of the reaction temperature, may enable selective operation of PGL **100** or PGL **200** for either pyrolysis or low temperature gasification of the biomass feed. Low temperature gasification may reduce heat loss from PGL **100** or PGL **200** and increase the thermal efficiency of the pyrolysis or gasification processes.

[0036] To the extent that the term “includes” or “including” is used in the specification or the claims, it is intended to be inclusive in a manner similar to the term “comprising” as that term is interpreted when employed as a transitional word in a claim. Furthermore, to the extent that the term “or” is employed (e.g., A or B) it is intended to mean “A or B or both.” When the applicants intend to indicate “only A or B but not both” then the term “only A or B

but not both” will be employed. Thus, use of the term “or” herein is the inclusive, and not the exclusive use. See Bryan A. Garner, *A Dictionary of Modern Legal Usage* 624 (2d. Ed. 1995). Also, to the extent that the terms “in” or “into” are used in the specification or the claims, it is intended to additionally mean “on” or “onto.” To the extent that the term “selectively” is used in the specification or the claims, it is intended to refer to a condition of a component wherein a user of the apparatus may activate or deactivate the feature or function of the component as is necessary or desired in use of the apparatus. To the extent that the term “operatively connected” is used in the specification or the claims, it is intended to mean that the identified components are connected in a way to perform a designated function. To the extent that the term “substantially” is used in the specification or the claims, it is intended to mean that the identified components have the relation or qualities indicated with degree of error as would be acceptable in the subject industry. As used in the specification and the claims, the singular forms “a,” “an,” and “the” include the plural. Finally, where the term “about” is used in conjunction with a number, it is intended to include $\pm 10\%$ of the number. In other words, “about 10” may mean from 9 to 11.

[0037] As stated above, while the present application has been illustrated by the description of embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art, having the benefit of the present application. Therefore, the application, in its broader aspects, is not limited to the specific details, illustrative examples shown, or any apparatus referred to. Departures may be made from such details, examples, and apparatuses without departing from the spirit or scope of the general inventive concept.

CLAIMS

1. A single pyrolysis gasification loop for pyrolyzing a biomass material, the single pyrolysis gasification loop comprising:
 - a reactor auger operatively connected to at least one of a biomass inlet and a vapor outlet; and
 - a return auger;
 - wherein the reactor auger and the return auger are operatively connected by at least one of a reactor outlet and a return outlet;
 - wherein the reactor auger is operable to advance the biomass material to the return auger via the reactor outlet;
 - wherein the return auger is operable to advance the biomass material to the reactor auger via the return outlet; and
 - wherein the reactor auger is operable to pyrolyze the biomass material.
2. The single pyrolysis gasification loop of claim 1, wherein the reactor auger is operatively connected to the biomass inlet and the vapor outlet.
3. The single pyrolysis gasification loop of claim 1, wherein the reactor auger and the return auger are operatively connected by the reactor outlet and the return outlet.
4. The single pyrolysis gasification loop of claim 1, wherein the biomass inlet is operable to intake the biomass material into the single pyrolysis gasification loop.
5. The single pyrolysis gasification loop of claim 1, wherein the vapor outlet is operable to outlet a pyrolysis vapor from the single pyrolysis gasification loop.
6. The single pyrolysis gasification loop of claim 1, wherein the single pyrolysis gasification loop is operable to generate a low oxygen bio oil.
7. The single pyrolysis gasification loop of claim 1, wherein the single pyrolysis gasification loop is operable to generate a syn gas.

8. The single pyrolysis gasification loop of claim 1, further comprising a phase change material surrounding at least one of the reactor auger and the return auger.

9. The single pyrolysis gasification loop of claim 1, wherein at least one of the reactor auger and the return auger contain a heating media.

10. The single pyrolysis gasification loop of claim 1, wherein the reactor auger is operatively connected to a reactor motor and the return auger is operatively connected to a return motor.

11. A single pyrolysis gasification loop for gasifying a char material, the single pyrolysis gasification loop comprising:

a reactor auger operatively connected to at least one of a heat inlet and a gas outlet; and

a return auger;

wherein the reactor auger and the return auger are operatively connected by at least one of a reactor outlet and a return outlet;

wherein the reactor auger is operable to advance the char material to the return auger via the reactor outlet;

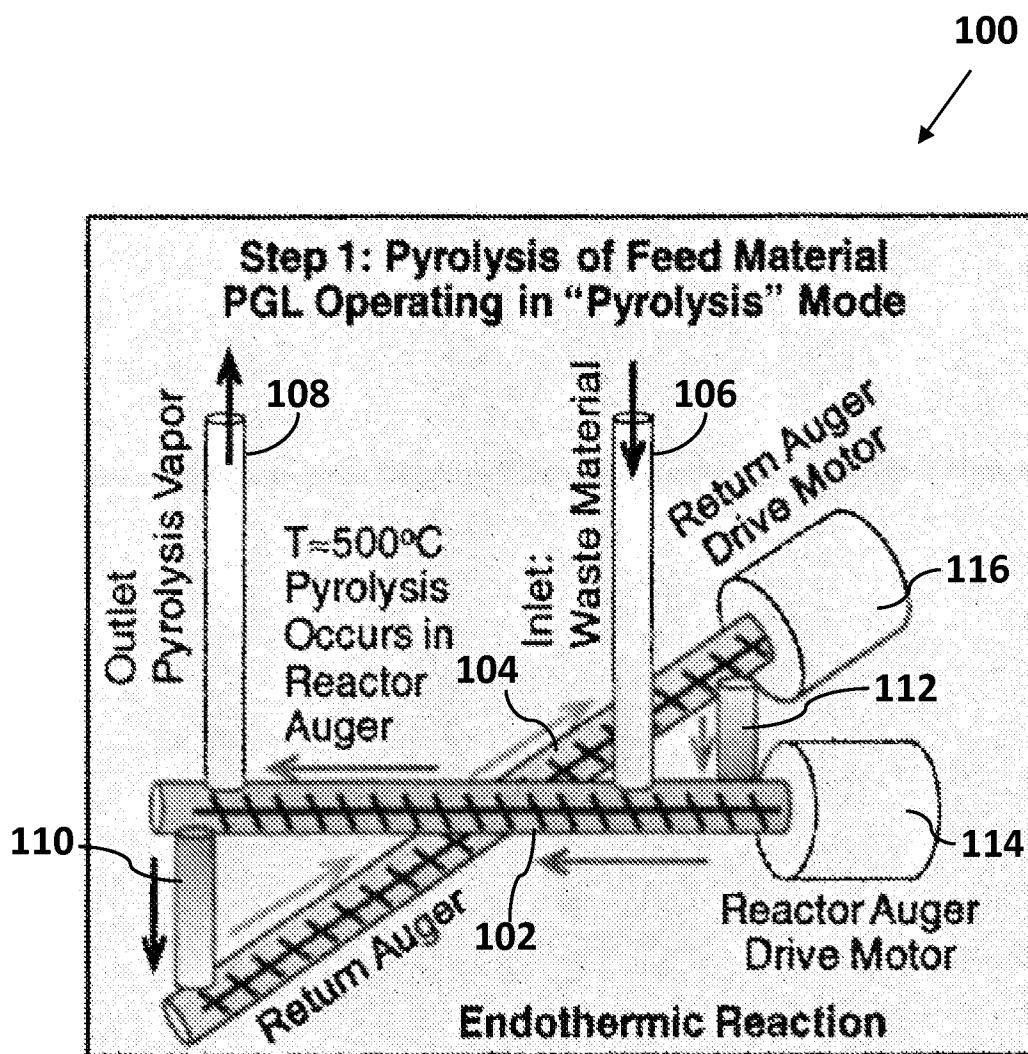
wherein the return auger is operable to advance the char material to the reactor auger via the return outlet; and

wherein the reactor auger is operable to gasify the char material.

12. The single pyrolysis gasification loop of claim 11, wherein the reactor auger is operatively connected to the heat inlet and the gas outlet.

13. The single pyrolysis gasification loop of claim 11, wherein the reactor auger and the return auger are operatively connected by the reactor outlet and the return outlet.

14. The single pyrolysis gasification loop of claim 11, wherein the heat inlet is operable to intake at least one of a steam or a heated air into the single pyrolysis gasification loop.
15. The single pyrolysis gasification loop of claim 11, wherein the gas outlet is operable to outlet a gas from the single pyrolysis gasification loop.
16. The single pyrolysis gasification loop of claim 11, wherein the single pyrolysis gasification loop is operable to generate a syn gas.
17. The single pyrolysis gasification loop of claim 11, further comprising a phase change material surrounding at least one of the reactor auger and the return auger.
18. The single pyrolysis gasification loop of claim 11, wherein at least one of the reactor auger and the return auger contain a heating media.
19. The single pyrolysis gasification loop of claim 11, wherein the reactor auger is operatively connected to a reactor motor and the return auger is operatively connected to a return motor.
20. The single pyrolysis gasification loop of claim 11, further comprising at least one damper operable to managed a reactor temperature.

**FIG. 1**

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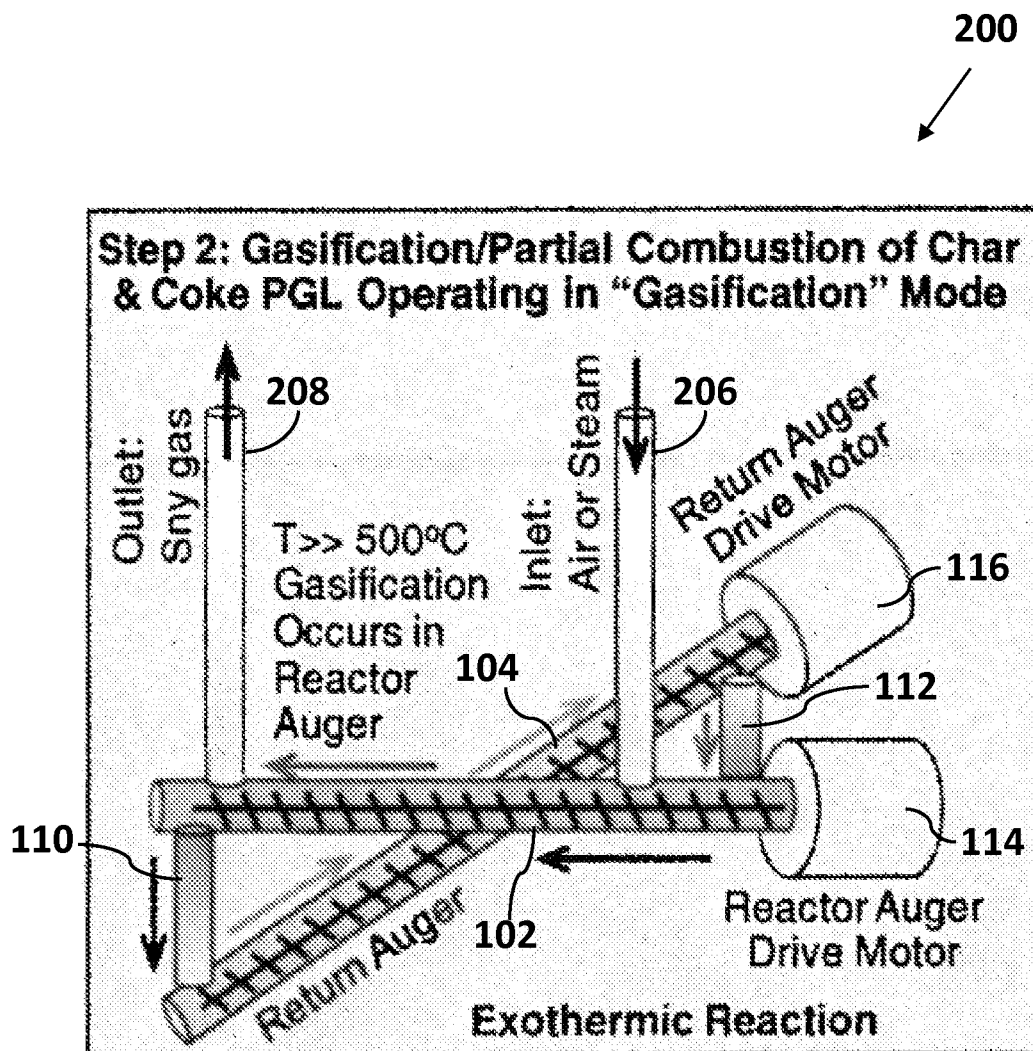


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/029920

A. CLASSIFICATION OF SUBJECT MATTER
INV. C10J3/00 C10J3/66
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C10J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 323 810 A1 (VON GOERTZ & FINGER TECHN ENTW [DE]) 2 July 2003 (2003-07-02) paragraph [0003] - paragraph [0004]; figure 1 -----	1-20
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A	DE 10 2006 013617 A1 (UNIV KASSEL [DE]) 27 September 2007 (2007-09-27) the whole document ----- -/-	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

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"&" document member of the same patent family

Date of the actual completion of the international search

4 July 2014

Date of mailing of the international search report

14/07/2014

Name and mailing address of the ISA/

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Authorized officer

Iyer-Baldew, A

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/029920

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/149471 A1 (WOLFE RICHARD A [US]) 26 June 2008 (2008-06-26) the whole document -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/029920

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