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(54) **PLANT FOR THE FLASH OR FAST PYROLYSIS OF CARBONACEOUS MATERIALS**

(76) Inventors: **Phillip C. Badger**, Florence, AL (US); **Joshua H. McGill**, Muscle Shoals, AL (US)

Correspondence Address:
WELSH FLAXMAN & GITLER LLC
2000 DUKE STREET, SUITE 100
ALEXANDRIA, VA 22314 (US)

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(52) **U.S. Cl.** **44/639**

(57) **ABSTRACT**

A fast pyrolysis system employs a plant for use in the processing of bio-fuels. The plant includes a base frame having a first end and a second end, as well as a first lateral side and a second lateral side. The plant also includes an inlet shaped and dimensioned for the input of carbonaceous feedstock mounted to the base frame adjacent the first end, a reactor chamber mounted to the base frame and coupled to the inlet by a feed mechanism which directs carbonaceous feedstock from the inlet to the reactor chamber, a condenser system positioned and supported along the first lateral side of the base frame by a vertical supporting framework, a char separation and recovery system mounted upon the base frame and coupled to the reactor chamber by an auger for transporting char and heat carrier from the reactor chamber to the char separation and recovery system, and a heat exchanger circulating the heat carrier from the char separation and recovery system back to the reactor chamber. The system also includes an engine-generator linked to a furnace, wherein the engine-generator supplies heat to the furnace and the furnace boosts in temperature the heat generated by the engine-generator for use by the plant.

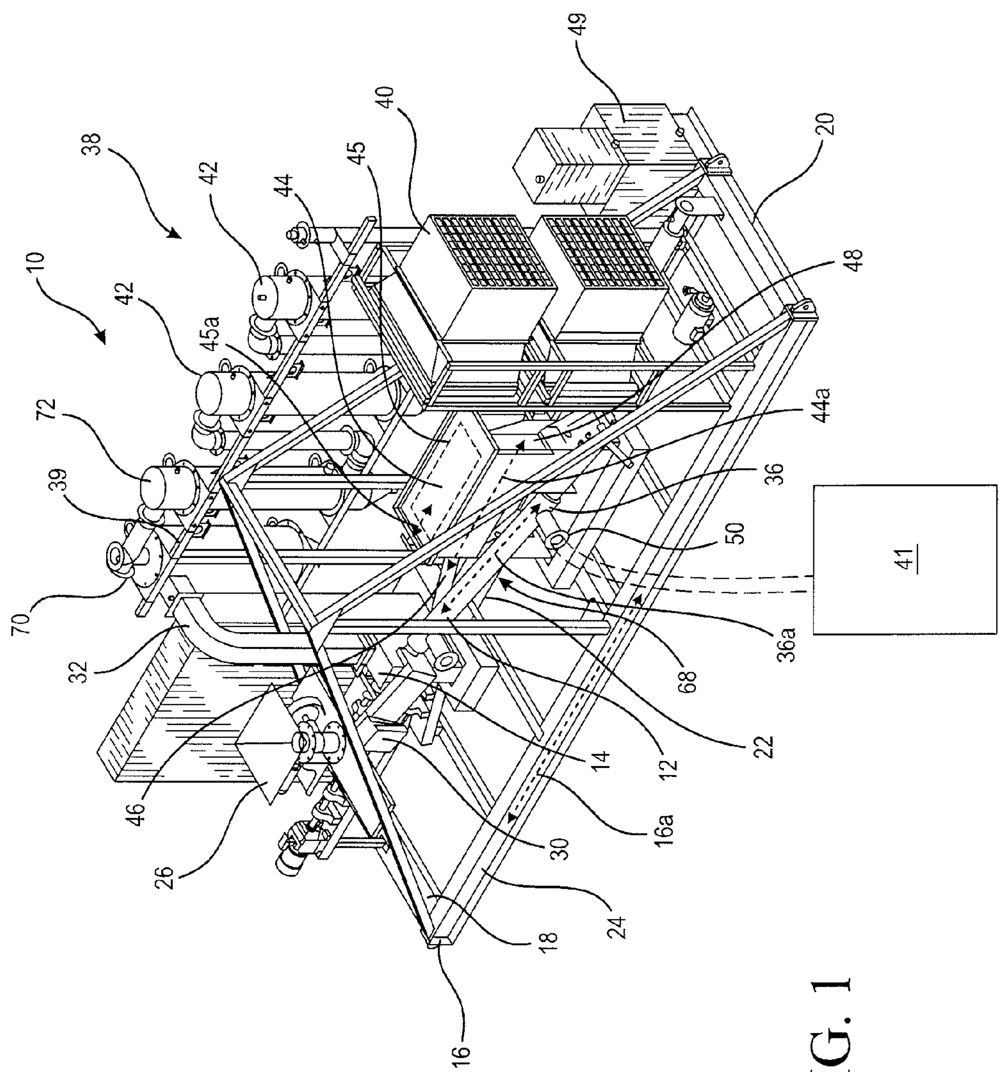

10
38
42
42
72
39
70
32
46
26
30
16a
14
12
22
68
36a
50
36
44a
48
45a
44
45
40
49
20
18
24
16
41

FIG. 1

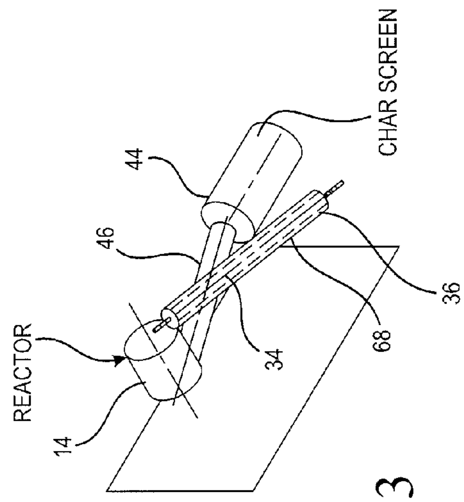


FIG. 3

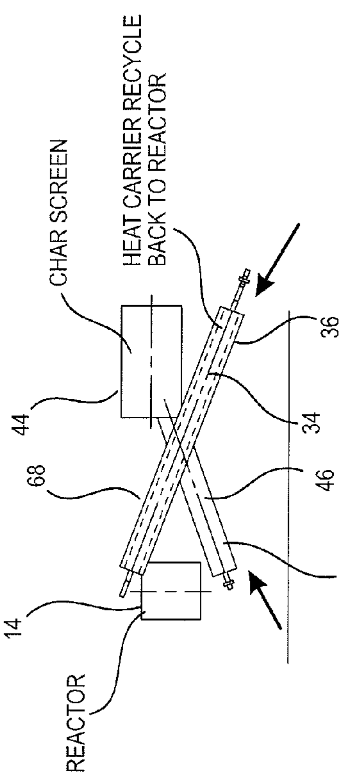
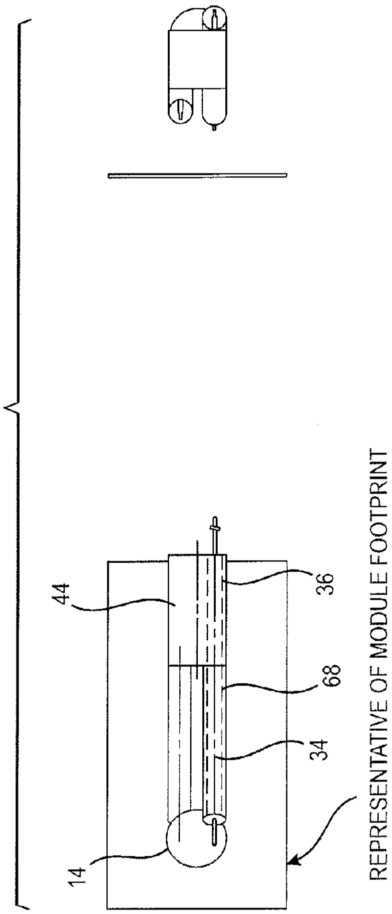


FIG. 2

FIG. 4



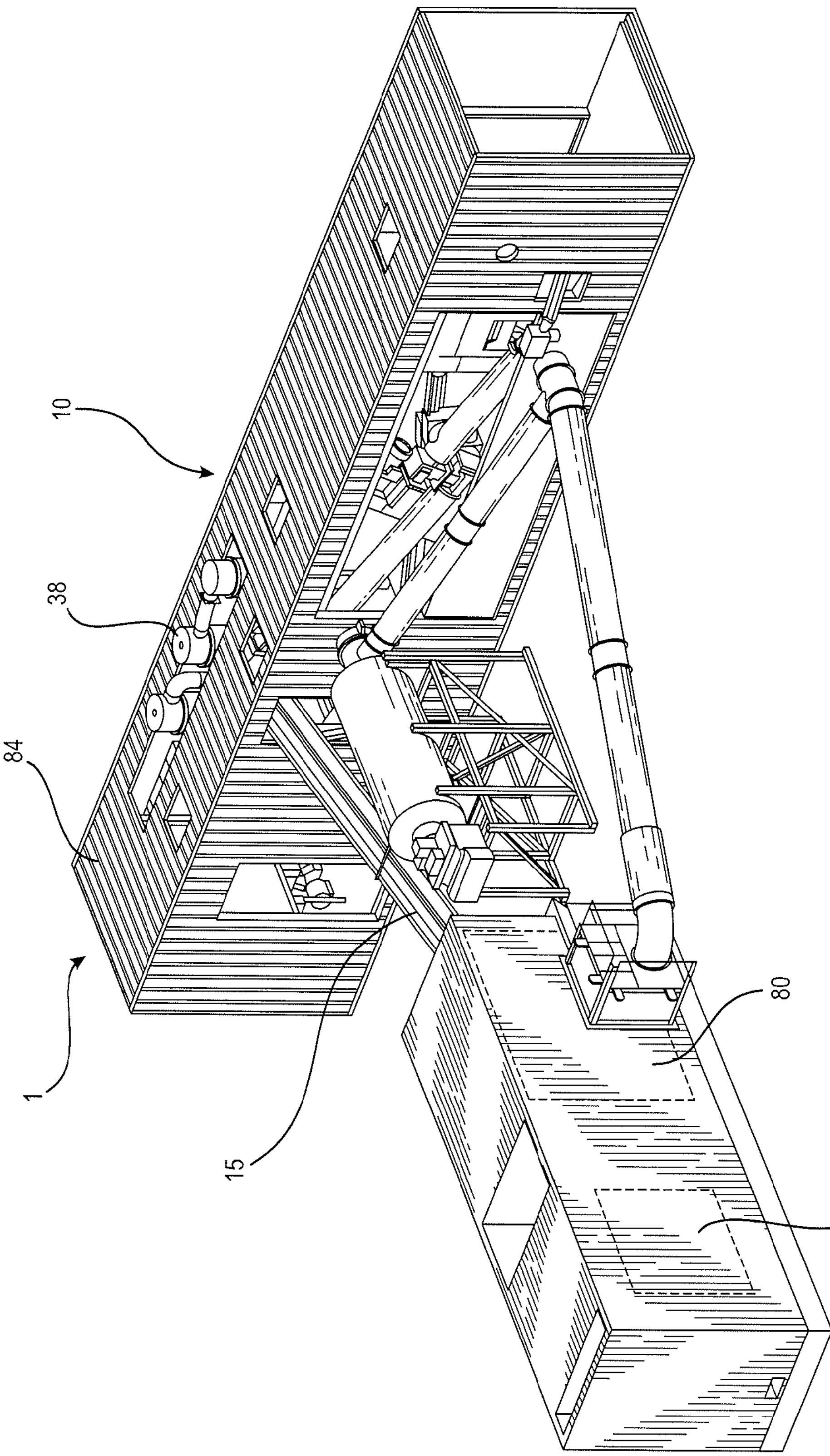


FIG. 5

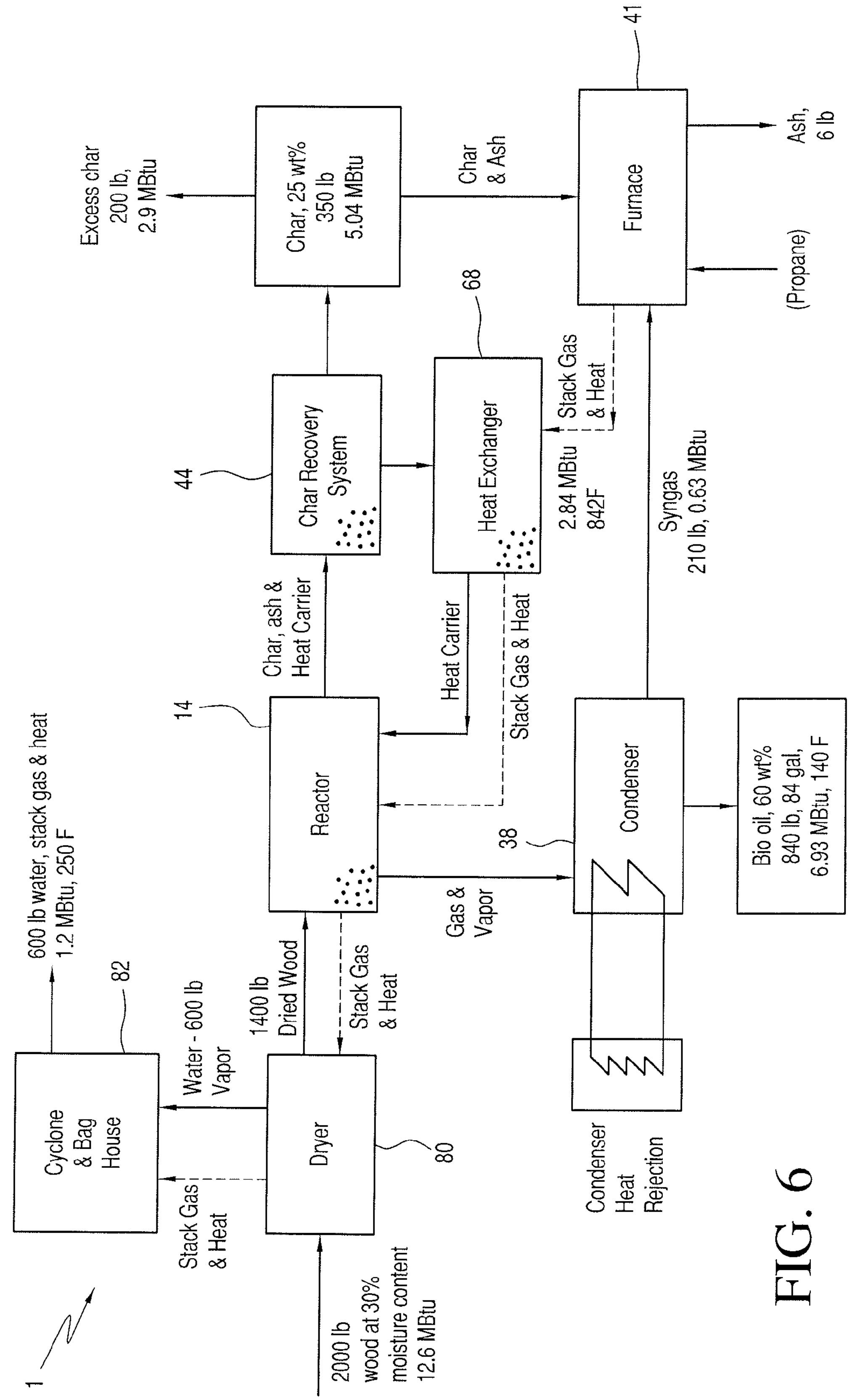

1
2000 lb
wood at 30%
moisture content
12.6 MBtu
Dryer
80
Stack Gas
& Heat
Cyclone
& Bag
House
82
Water - 600 lb
Vapor
600 lb water, stack gas & heat
1.2 MBtu, 250 F
1400 lb
Dried Wood
Stack Gas
& Heat
Reactor
14
Gas &
Vapor
Char, ash &
Heat Carrier
Heat Carrier
Stack Gas & Heat
Char Recovery
System
44
Heat Exchanger
68
2.84 MBtu
842F
Stack Gas
& Heat
Char, 25 wt%
350 lb
5.04 MBtu
Excess char
200 lb,
2.9 MBtu
Char
& Ash
Furnace
41
Ash,
6 lb
(Propane)
Syngas
210 lb, 0.63 MBtu
Condenser
38
Bio oil, 60 wt%
840 lb, 84 gal,
6.93 MBtu, 140 F
Condenser
Heat
Rejection

FIG. 6

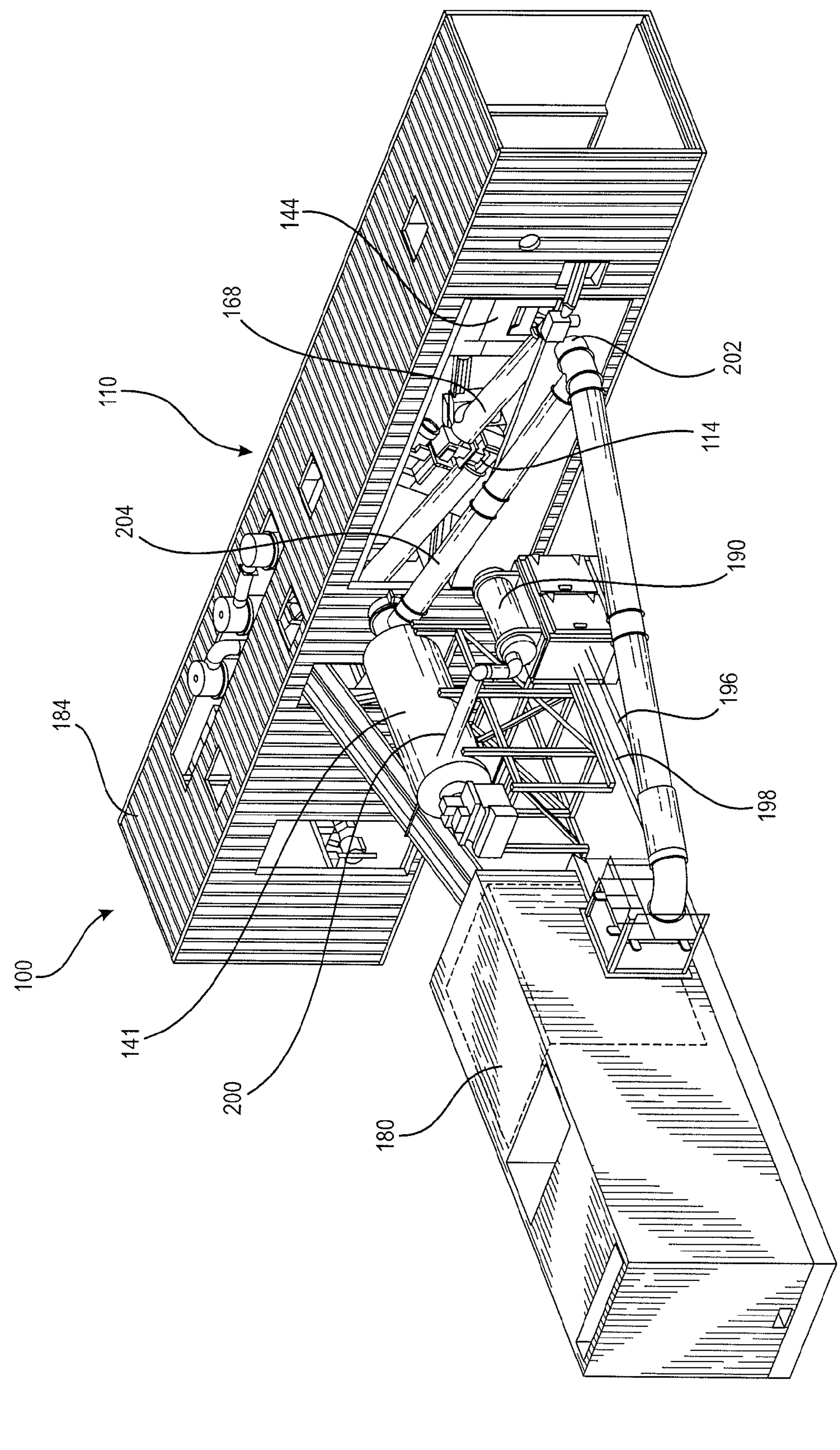


FIG. 7

FIG. 8

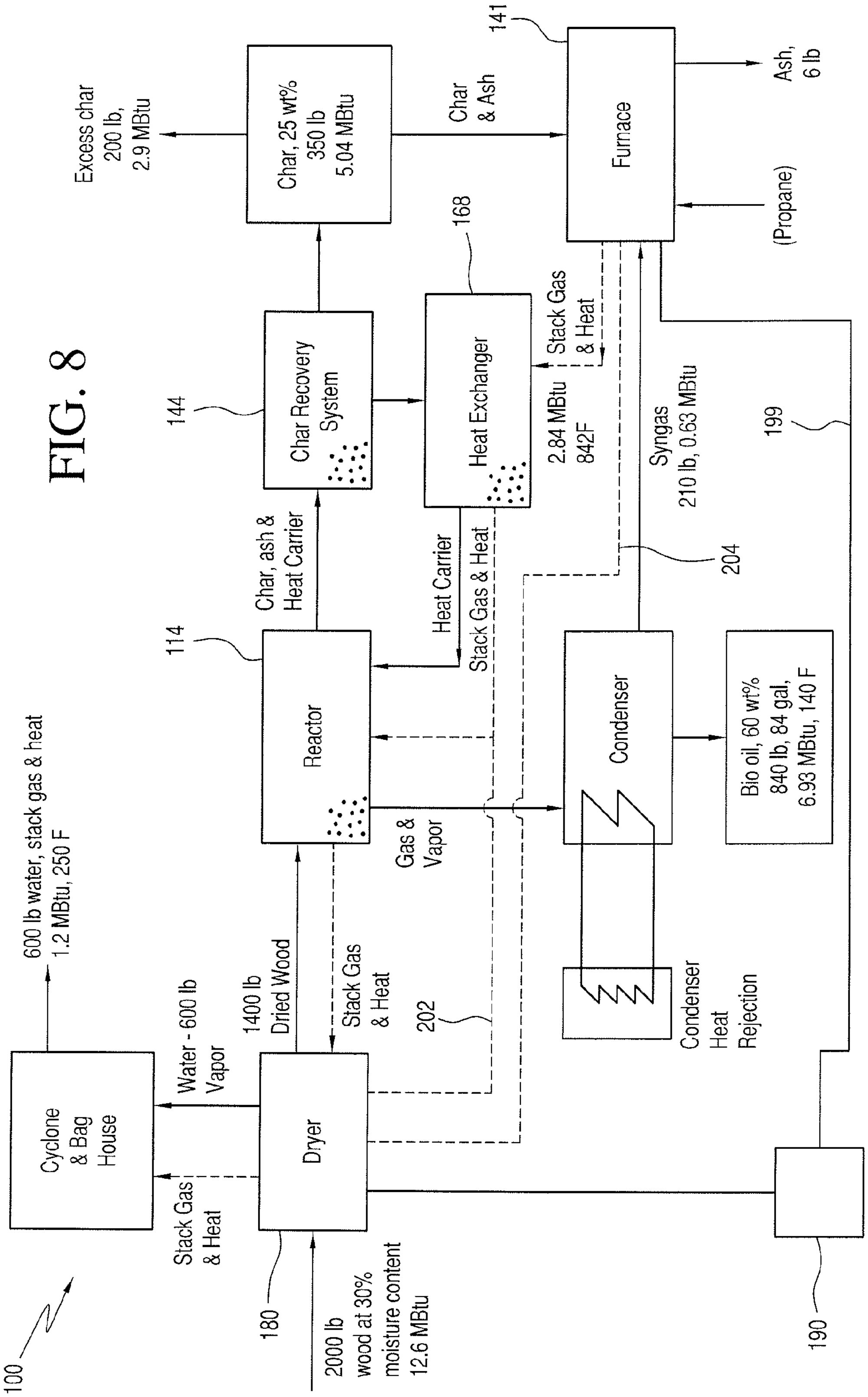
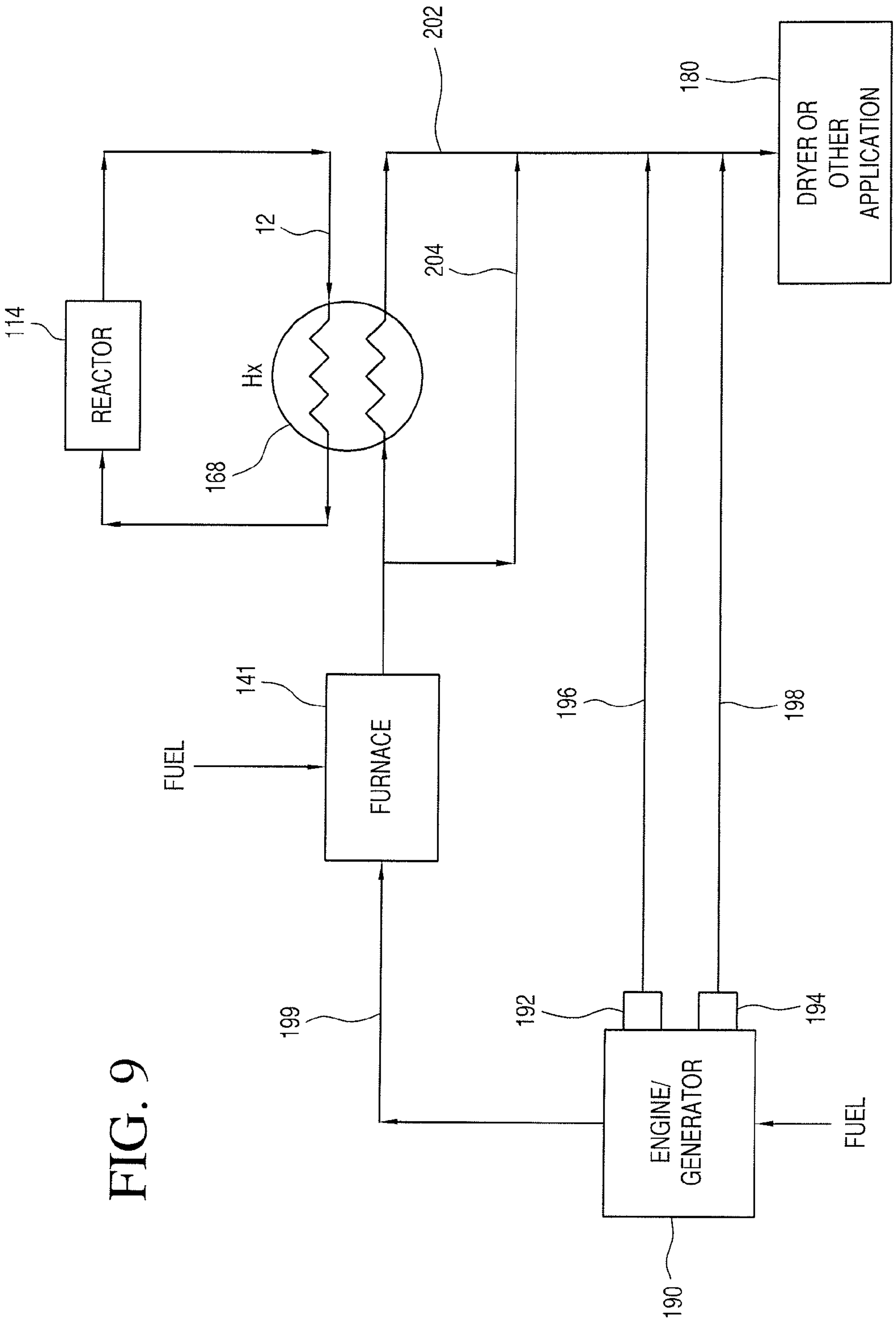

100
600 lb water, stack gas & heat
1.2 MBtu, 250 F
Cyclone & Bag House
Stack Gas & Heat
Water - 600 lb Vapor
Dryer
180
2000 lb wood at 30% moisture content 12.6 MBtu
1400 lb Dried Wood
Stack Gas & Heat
202
Reactor
114
Gas & Vapor
Char, ash & Heat Carrier
Char Recovery System
144
Heat Carrier
Stack Gas & Heat
Heat Exchanger
168
2.84 MBtu 842F
Stack Gas & Heat
Excess char 200 lb, 2.9 MBtu
Char, 25 wt% 350 lb 5.04 MBtu
Char & Ash
Furnace
141
Ash, 6 lb
(Propane)
Syngas 210 lb, 0.63 MBtu
204
Condenser
Condenser Heat Rejection
Bio oil, 60 wt% 840 lb, 84 gal, 6.93 MBtu, 140 F
199
190

FIG. 9


202
180
DRYER OR OTHER APPLICATION
114
REACTOR
12
204
Hx
168
141
FUEL
FURNACE
196
198
199
192
194
ENGINE/ GENERATOR
FUEL
190

PLANT FOR THE FLASH OR FAST PYROLYSIS OF CARBONACEOUS MATERIALS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/234,108, entitled "PLANT FOR THE FLASH OR FAST PYROLYSIS OF CARBONACEOUS MATERIALS", filed Aug. 14, 2009.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention The invention relates to a fast pyrolysis plant.

[0003] 2. Description of the Prior Art

[0004] Current worldwide demands for energy sources necessitate that additional energy sources be developed for efficiently and cost effectively providing energy. Researchers have attempted to develop renewable oil sources by converting carbonaceous feedstock, for example, biomass materials, into useful energy sources. Many of these processes rely upon the thermal decomposition, for example, pyrolysis, of the feedstock for converting the feedstock into readily usable energy sources.

[0005] While some success has been found through the utilization of prior systems, a need still exists for an improved and more efficient process for the conversion of carbonaceous feedstock to useful energy sources. The present invention provides such a process.

SUMMARY OF THE INVENTION

[0006] It is, therefore, an object of the present invention to provide a pyrolysis system including a plant for use in the processing of bio-fuels including a base frame having a first end and a second end, as well as a first lateral side and a second lateral side. The plant includes an inlet shaped and dimensioned for the input of carbonaceous feedstock mounted to the base frame adjacent to the first end. A reactor chamber is mounted to the base frame and coupled to the inlet by a feed mechanism which directs carbonaceous feedstock from the inlet to the reactor chamber. A condenser system is positioned and supported along the first lateral side of the base frame by a vertical supporting framework. A char separation and recovery system is mounted upon the base frame and coupled to the reactor chamber by a conveying mechanism for transporting char and heat carrier from the reactor chamber to the char separation and recovery system. The char separation and recovery system is positioned so that its long axis is parallel to the long axis of the base frame. A heat exchanger circulates the heat carrier from the char separation and recovery system back to the reactor chamber.

[0007] It is also an object of the present invention to provide a pyrolysis system wherein the plant is shaped and dimensioned for placement within a container suitable for over-the-road transportation.

[0008] It is another object of the present invention to provide a pyrolysis system wherein the shipping container has a volume of approximately 3,648 cubic feet.

[0009] It is a further object of the present invention to provide a pyrolysis system including a dryer in communication with the inlet.

[0010] It is also an object of the present invention to provide a pyrolysis system including an engine-generator.

[0011] It is another object of the present invention to provide a pyrolysis system wherein the engine-generator supplies heat to the heat exchanger.

[0012] It is a further object of the present invention to provide a pyrolysis system including a dryer in communication with the inlet and wherein the engine generator supplies heat to the dryer.

[0013] It is also an object of the present invention to provide a pyrolysis system wherein the engine-generator is fueled with syngas or the liquid fuel product generated as a result of operation of the present plant.

[0014] It is another object of the present invention to provide a pyrolysis system wherein a radiator is linked to the engine-generator and heat recovered from the engine radiator for use by the plant or other application.

[0015] It is a further object of the present invention to provide a pyrolysis system wherein a crankcase oil cooler is linked to the engine-generator and heat recovered from the engine oil cooler for use by the plant or other application.

[0016] It is also an object of the present invention to provide a pyrolysis system including a furnace, wherein the engine-generator supplies heat to the furnace and the furnace boosts in temperature the heat generated by the engine-generator.

[0017] It is another object of the present invention to provide a pyrolysis system for use in the processing of bio-fuels including a base frame having a first end and a second end, as well as a first lateral side and a second lateral side. The plant includes an inlet shaped and dimensioned for the input of carbonaceous feedstock mounted to the base frame adjacent to the first end with a dryer in communication with the input. A reactor chamber is mounted to the base frame and coupled to the inlet by a feed mechanism which directs carbonaceous feedstock from the inlet to the reactor chamber. A condenser system is positioned and supported along the first lateral side of the base frame by a vertical supporting framework. A char separation and recovery system is mounted upon the base frame and coupled to the reactor chamber by a conveying mechanism for transporting char and heat carrier from the reactor chamber to the char separation and recovery system. A heat exchanger circulates the heat carrier from the char separation and recovery system back to the reactor chamber. An engine-generator is linked to a furnace, wherein the engine-generator supplies heat to the furnace and the furnace boosts in temperature the heat generated by the engine-generator for use by the plant.

[0018] Other objects, advantages and salient features of the invention will become apparent from the following detailed description, which taken in conjunction with the annexed drawings, discloses a preferred, but non-limiting, embodiment of the subject invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. **1** is a perspective view of the present plant.

[0020] FIGS. **2**, **3** and **4** are schematics showing the relationship between the reactor chamber and the char separation and recovery system.

[0021] FIG. **5** is a perspective view of the present plant within a shipping container and with associated components attached thereto.

[0022] FIG. **6** is a flow chart showing operation of the present fast pyrolysis system.

[0023] FIG. **7** is a perspective view of an alternate embodiment of the present plant within a shipping container and with associated components attached thereto.

[0024] FIGS. **8** and **9** are flow charts showing operation of the alternate system shown with reference to FIG. **7**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] The detailed embodiments of the present invention are disclosed herein. It should be understood, however, that the disclosed embodiments are merely exemplary of the invention, which may be embodied in various forms. Therefore, the details disclosed herein are not to be interpreted as limiting, but merely as a basis for teaching one skilled in the art how to make and/or use the invention.

[0026] Referring to FIGS. **1** to **6**, a fast pyrolysis system **1** employing a plant **10** for use in the processing of bio-fuels is disclosed. Generally, the plant **10** converts carbonaceous feedstock into energy, such as, gaseous, liquid and char products in accordance with the present invention. The carbonaceous feedstock may, for example, be biomass. In order for the present plant **10** to work properly, the feedstock must be ground to a fine consistency and dried. The plant **10** generally implements the same components and concepts for the processing of bio-fuels as disclosed in commonly owned U.S. patent application Ser. No. 11/480,914, filed Jul. 6, 2006, which was been published as U.S. Patent Application Publication No. 2008/0006519 on Jan. 10, 2008, entitled "METHOD AND SYSTEM FOR ACCOMPLISHING FLASH OR FAST PYROLYSIS WITH CARBONACEOUS MATERIALS", which is incorporated herein by reference.

[0027] Briefly, and with reference to FIG. **6**, a flow chart of the fast pyrolysis system **1** and process is shown. The resulting char and coproducts may be used in various applications for the creation of heat and energy, or for other applications. As those skilled in the art will appreciate, the term "char" is meant to refer to carbon-rich matter that has been partially, but incompletely, devolatized when subjected to heat in a controlled manner for a predetermined period of time. The application of heat to the feedstock in an oxygen depleted atmosphere results in the removal of some hydrogen, oxygen and carbon from the feedstock, leaving a char material primarily composed of carbon.

[0028] The fast pyrolysis process as implemented through the use of the present plant **10** employs a dryer **80** into which carbonaceous feedstock, such as biomass, for example, wood at 30% moisture content and having approximately 12.6 MBtu of available energy, is placed. In order for the present system **1** to work properly, the feedstock must be ground to a fine consistency and dried. As those skilled in the art will certainly appreciate, the equipment used in grinding and drying of the feedstock is readily available, and various known devices may be employed for this purpose.

[0029] From the dryer **80**, which may be heated from waste heat from an associated reactor chamber **14** or from another source (as discussed below in accordance with an alternate embodiment), the dried feedstock is forwarded to the reactor chamber **14** via a conveyor **15** and inlet **26** with the emissions from the dryer **80** forwarded to a cyclone and/or bag house **82** (or other suitable device which removes pollutants from the emission stream). It is contemplated that where the drying of carbonaceous materials may generate other emissions, for example, volatile organic compounds (VOCs), the cyclone and/or bag house **82** may be replaced or supplemented with a wet scrubber or other suitable device known to those skilled in the art for the control of emissions. The dried biomass, for example, the dried wood, is transferred to the reactor chamber **14** which operates at approximately 662° F. (350° C.) to approximately 1,040° F. (560° C.). While drying of the feedstock is disclosed in accordance with a preferred embodiment of the present invention, those skilled in the art will appreciate that drying is not always necessary as some feedstock arrives dry enough for processing and the drying step may be skipped.

[0030] Gas and vapor from the reactor chamber **14** is passed through a condenser system **38** as discussed below in greater detail and the vapor is condensed to recover the liquid product. This liquid product is known by several names including bio-oil, pyrolysis oil, wood distillate, and other names, and is composed of water and numerous chemicals. Useful gas, for example, syngas, is recovered as it exits the condenser system **38**. The bio-oil is collected for later use and the syngas is forwarded to a furnace **41**, where it is combusted to provide at least part of the energy for the fast pyrolysis process. Alternatively, the syngas could be used to fuel an engine to generate heat and electricity for the system or used in other ways, such as feedstock for chemical production or for applications separate from the fast pyrolysis plant. As those skilled in the art will appreciate, syngas (or synthesis gas) is the non-condensable gas portion of the gas and vapor stream from the reactor chamber **14** and has energy value. The bio-oil may be used as an energy source or a source of chemicals, or for other applications, in much the same manner as petroleum products.

[0031] The char (and its inherent ash) and heat carrier **12** are transferred from the pyrolytic reactor chamber **14** to the char separation and recovery system **44**. The char separation and recovery system **44** separates the heat carrier (HC) **12**, which is transferred to a heat exchanger **68** to be reheated and recirculated to the reactor chamber **14**, and the char, which is collected and, to the extent necessary needed for process energy, burned in the furnace **41**. Any char not needed for process energy becomes a coproduct. The hot heat carrier **12**, when mixed with the feedstock in the reactor chamber **14**, provides the thermal energy for pyrolysis to occur in the reactor chamber **14** without the introduction of oxygen into the reactor chamber **14**.

[0032] With this in mind, and in accordance with a preferred embodiment of the present invention, the method is achieved by drying carbonaceous feedstock (if necessary), processing the dried carbonaceous feedstock with heat from the heat carrier **12** in a reactor chamber **14**, separating char produced as a result of processing of feedstock within the reactor chamber **14** from heat carrier **12**, separating and recovering liquid product and non-condensable gases from gas and vapor emitted by the reactor chamber **14**, and burning the non-condensable gases and char as needed to provide energy for operation of the method.

[0033] If the plant is not mounted in a modular configuration (which could be a shipping container), the plant **10** may include a base frame **16** upon which the operating components of the processing plant **10** are mounted. If mounted within a modular container **84**, the container **84** itself can serve as the plant frame. The processing plant **10** is specifically designed for positioning within standard size shipping containers, although small portions may extend beyond the walls of the container **84** as shown with regard to the condenser system **38** shown in FIG. **3**. In accordance with a preferred embodiment, the plant **10** should fit within an 9.5 foot (290 cm) (width) by 8 foot (244 cm) (height) by 48 foot (1463 cm) (length) container (occupying approximately

3,648 cubic feet (104 cubic meters) of space)) used in overseas shipping or similar module suitable for over-the-road transportation as governed by the United States Department of Transportation, Rules and Regulations, Part 658, Size and Weight, Route Designations—Length, Width and Weight Limitations, which is incorporated herein by reference, for ease of distribution and installation. Accordingly, where a base frame is used, the base frame **16** is typically constructed of metal fastened (for example, welded) together in a rectangular configuration. The base frame **16** includes a first end **18** and a second end **20**, as well as a first lateral side **22** and a second lateral side **24**.

[0034] An inlet **26** is mounted to the base frame **16** adjacent the first end **18**. The inlet **26** is shaped and dimensioned for the input of carbonaceous feedstock. It is contemplated the inlet **26** may be connected to the dryer **80** via a conveyor **15** as shown in FIG. **5**. As those skilled in the art will certainly appreciate, the equipment used in grinding and drying of the feedstock is readily available, and various known devices may be employed for this purpose.

[0035] The carbonaceous feedstock is directed from the inlet **26** to the reactor chamber **14** by virtue of a feed mechanism **30**. In accordance with a preferred embodiment, the feed mechanism **30** includes a rotating feed auger. In accordance with a preferred embodiment, the rotating feed auger is a conventional centerless auger (i.e., shaftless auger), although an auger with a center shaft may be used, in a tube or one or more side-by-side augers which may or may not be in a common trough as disclosed in commonly owned U.S. patent application Ser. No. 11/480,914, filed Jul. 6, 2006, which was been published as U.S. Patent Application Publication No. 2008/0006519 on Jan. 10, 2008, entitled "METHOD AND SYSTEM FOR ACCOMPLISHING FLASH OR FAST PYROLYSIS WITH CARBONACEOUS MATERIALS", which is incorporated herein by reference.

[0036] The distance is increased between the feed point and the reactor chamber **14** so as to reduce burn back and to form a better air seal, since it is necessary to maintain oxygen depleted conditions inside the reactor chamber **14**. As briefly discussed above, and in accordance with a preferred embodiment of the present invention, the feed mechanism **30** is composed of a rotating feed auger with a motorized star wheel airlock (not shown) positioned above the rotating feed auger and at the auger end opposite the reactor chamber **14**. The motorized star wheel airlock drops material through an air gap into the rotating feed auger to improve the air seal and reduce the chances for burn back. The airlock is more important for granular, or other, materials that do not naturally compact when conveyed by an auger.

[0037] The reactor chamber **14** is mounted at the first end **18** of the base frame **16** adjacent the inlet **26**. Where a dryer **80** is used, the emissions from the dryer **80** are forwarded to a cyclone and/or bag house **82** or other emission control devices, if emission control devices are necessary. It is contemplated that where the drying of carbonaceous materials may generate other emissions, for example, volatile organic compounds, the cyclone and/or bag house may be replaced or supplemented with a wet scrubber or other suitable device known to those skilled in the art for the control of emissions. While drying of the feedstock is disclosed in accordance with a preferred embodiment of the present invention, those skilled in the art will appreciate that drying is not always necessary as some feedstock arrives dry enough for processing and the drying step may be skipped.

[0038] The dry biomass, for example, the dried wood, is transferred to the reactor chamber **14** which operates at approximately 662° F. (350° C.) to approximately (1040° C.) 560° C. More particularly, after passing through the feed mechanism **30**, the carbonaceous feedstock enters the pyrolytic reactor chamber **14**, which houses a rotating auger or some other mixing device (not shown), and wherein the feed stock is mixed with a heat carrier **12**. The carbonaceous feedstock is formed into plugs as the feedstock is conveyed by the feed mechanism **30**. The formation of plugs excludes air from the reactor chamber **14**. In accordance with a preferred embodiment of the present invention, the heat carrier **12** is hot steel shot, although a variety of heat carriers may be utilized without departing from the spirit of the present invention.

[0039] The gas and vapor generated by the reactor chamber **14** are passed through a condenser system **38**. The condenser system **38** is positioned and supported along the first lateral side **22** of the base frame **16** by a vertical supporting framework **39** and is also positioned adjacent the reactor chamber **14** for easy transmission of the gas and vapor products thereto. The liquid product produced in accordance with the present plant **10** is known by several names including bio-oil, pyrolysis oil, wood distillate and other names, and is composed of water and numerous chemicals. Useful gas, for example, syngas is recovered as it exits the condenser system **38**. The bio-oil is collected for later use and the syngas is forwarded to a furnace **41** (that is, the char/syngas/bio-oil burner that may be connected to the plant **10** for receipt of the bio-oil) where it is combusted to provide at least part of the energy for the plant **10**. Alternatively, the syngas could be used to fuel an engine (which can be in various forms) to generate heat and electricity for the plant **10**. As those skilled in the art will certainly appreciate, syngas (or synthesis gas) is the non-condensable gas portion of the gas and vapor stream from the reactor chamber **14** and has energy value. The bio-oil may be used as an energy source or a source of chemicals, or for other applications, in much the same manner as petroleum products.

[0040] More particularly, the gas and vapor depart the pyrolytic reactor chamber **14** via a tube **32** and are directed to the condenser system **38** or, alternatively, the gas and vapor—comprising a syngas—may be used for energy directly without a condenser system **38**. Condensed liquids, for example, bio-oil, are collected by virtue of tanks and then transferred with pumps. Prior to entering the condenser system **38**, the gas and vapor are cleansed by passing it through a char trap **70** and a tar trap **72**, as well as other suitable cleansing devices (also positioned and supported along the first lateral side **22** of the base frame **16** by the vertical supporting framework **39**). The cleansed vapor and gaseous material are then directed to a condenser system **38** and the condensed liquids (for example, including bio-oil) from the condenser system **38** are transferred to storage tanks **49** by gravity or by virtue of one or more liquid transfer pumps. The condenser system **38** is in fluid communication with a fluid air heat exchanger **40** mounted at the second end **20** of the base frame **16**.

[0041] The uncondensed gases, which can contain considerable energy value (for example in the form of syngas), are also recovered and used for energy by directing them to a char/syngas/bio-oil burner, that is, a furnace, **41** or for applications independent of the pyrolysis process. The uncondensed gases may be used for energy by using the uncondensed gases to fuel an engine (for example, reciprocating internal combustion engine, combustion turbine, or Stirling engine) to provide mechanical and/or electrical power and heat for the process. Depending upon the type of feedstock and the feedstock moisture content, there can be enough energy in the uncondensed gas to supply all the electrical and/or heat requirements of the present plant **10**. The use of the uncondensed gas, bio-oil, and char can thus minimize or eliminate the need for external energy sources which reduces operating expense and may allow the units to be operated in remote areas (for example, military camps and/or logging camps).

[0042] In accordance with a preferred embodiment, one or more fractional condensation columns **42** may be employed. As those skilled in the art will appreciate, and as discussed in greater detail in U.S. patent application Ser. No. 11/480,914, filed Jul. 6, 2006, which was published as U.S. Patent Application Publication No. 2008/0006519 on Jan. 10, 2008, entitled "METHOD AND SYSTEM FOR ACCOMPLISHING FLASH OR FAST PYROLYSIS WITH CARBONACEOUS MATERIALS", which is incorporated herein by reference, fractional condensation column(s) **42** include a series of plates which are connected directly to the reactor chamber(s) **14** (typically above the reactor chamber **14** to take advantage of the tendency of the warm, low-density vapor to rise) to create an integral unit so that the gas and vapor generated by the process in the reactor chamber **14** are continuously and immediately passed through the condensation columns **42**. Alternatively, the fractional condensers could take other forms and be located separately from the reactor chamber and connected to the reactor chamber by ducting or piping.

[0043] By coupling the reactor chamber **14** with fractional condensation columns **42** as described above, a simplified, continuous method of recovering various chemicals from condensed liquid is achieved. This minimizes or eliminates the need for additional processing of the liquid (which requires additional equipment, energy and cost) in order to recover chemicals from the liquid product. It also reduces cost since an additional extraction, upgrading, separation, and/or other system is not necessary to recover the chemicals and multiple, individual condensers are not required.

[0044] The char, ash and heat carrier **12** are transferred from the pyrolytic reactor chamber **14** to the char separation and recovery system **44** mounted at an opposite end of the base frame from the reactor chamber **14**. The preferred embodiment of the char separation and recovery system **44** includes a trommel screen inclined at an angle from zero to 15 degrees. The char separation and recovery system **44** is positioned so that its long axis **44*a*** is parallel to the long axis **16*a*** of the shipping container **84** and base frame **16**, and the vertical plane in which the axis **36*a*** of augers **34** and **46** lies is parallel to the vertical plane in which the long axis **16*a*** of the base frame **16** and the shipping container **84** lie. More particularly, the char, ash and the heat carrier **12** exit the pyrolytic reactor chamber **14** and are transported via an auger (or other conveying mechanism) **46** to the separation and recovery system **44** in which the heat carrier **12** is recovered for further use and separated from the char. Once the char and heat carrier **12** are separated, the char (which contains the feedstock ash) is passed to a char storage hopper (not shown) via an outlet **48** of the separation and recovery system **44** (or some other conveying mechanism). From there, char product is removed and, as needed for process heat, a portion of the char is transported to the char/syngas/bio-oil burner (or furnace) **41**. In particular, char is separated out from the heat carrier **12** by the separation and recovery system **44**, and conveyed via the outlet **48** to a lock hopper (not shown) for storage. In accordance with a preferred embodiment, the separation and recovery system **44** employs mechanisms as disclosed in commonly owned U.S. patent application Ser. No. 11/480,914, filed Jul. 6, 2006, which was been published as U.S. Patent Application Publication No. 2008/0006519 on Jan. 10, 2008, entitled "METHOD AND SYSTEM FOR ACCOMPLISHING FLASH OR FAST PYROLYSIS WITH CARBONACEOUS MATERIALS", which is incorporated herein by reference. As discussed in this published patent application the separation and recovery system **44** implements a trommel screen **45**, the long axis **45*a*** of which is aligned with the long axis **44*a*** of the separation and recovery system **44** such that it is oriented parallel to the long axis **16*a*** of the shipping container **84** and base frame **16**, just as the

[0045] The char separation and recovery system **44** separates the heat carrier **12**, which is transferred to a heat exchanger **68** to be reheated as it is recirculated to the reactor chamber **14**, and the char, which is collected and, to the extent necessary for process heat, burned in the furnace **41**. The heat carrier **12** is circulated back to the reactor chamber **14** via a heat exchanger **68** constructed as disclosed in commonly owned U.S. patent application Ser. No. 11/480,914, filed Jul. 6, 2006, which was been published as U.S. Patent Application Publication No. 2008/0006519 on Jan. 10, 2008, entitled "METHOD AND SYSTEM FOR ACCOMPLISHING FLASH OR FAST PYROLYSIS WITH CARBONACEOUS MATERIALS", which is incorporated herein by reference. Briefly, the heat exchanger **68** includes an auger mechanism **34** for conveying the heat carrier **12** and a heat exchanger chamber **36** surrounding the auger mechanism **34** for the transfer of heat thereto for application to the heat carrier **12** as it is moved by the auger mechanism **34**. The heat for the heat exchanger chamber **36** is supplied by the furnace **41** via a tube **50** connected between the heat exchanger **68** and the furnace **41**. Any char not needed for process heat becomes a coproduct. The hot heat carrier **12**, when mixed with the feedstock in the reactor chamber **14** after being transported by the heat exchanger **68**, provides the thermal energy for pyrolysis to occur in the reactor chamber **14** without the introduction of oxygen into the reactor chamber **14**.

[0046] In accordance with an additional aspect of the present invention, and with particular reference to FIGS. **7**, **8** and **9**, the present invention provides a methodology for energy self sufficiency for thermochemical processes processing carbonaceous materials, including fast pyrolysis processes, by minimizing the energy requirements of the process and by self-use of a portion of the energy products produced. As will be explained below, this is achieved by the integration of an engine-generator **190** into the fast pyrolysis system **100** employing the present plant **110**. With the exception of the integrated engine-generator **190** and the associated components discussed below, the structure and operation of the plant **110** remains the same as with the embodiment discussed above with regard to FIGS. **1** to **6**.

[0047] Although fast pyrolysis processes and other thermochemical processes show great potential to help meet our nation's need for liquid fuels that are not petroleum based, these processes continue to struggle to be cost competitive in today's economic environment. By reducing the need for external energy sources and using the energy produced by the process (which is generally the lowest cost energy available to energize the process) through the integration of an engine-generator **190** the present invention is capable of reducing the cost of process energy by up to one-third. Therefore, the present invention minimizes the energy requirements of an innovative fast pyrolysis process through energy recovery and, in combination with self-use of a portion of its energy products, can under some conditions, attain plant energy self-sufficiency.

[0048] The fast reaction times associated with fast pyrolysis means that large amounts of carbonaceous materials can be processed in a relatively small footprint as discussed and disclosed above with regard to the present processing plant **110** that is designed for positioning within standard size shipping containers **184** or to provide a readily transportable modular configuration for ease of distribution and installation. This feature, coupled with the simplicity of the fast pyrolysis technology discussed above and disclosed in commonly owned U.S. patent application Ser. No. 11/480,914, filed Jul. 6, 2006, which was been published as U.S. Patent Application Publication No. 2008/0006519 on Jan. 10, 2008, entitled "METHOD AND SYSTEM FOR ACCOMPLISHING FLASH OR FAST PYROLYSIS WITH CARBONACEOUS MATERIALS", which is incorporated herein by reference, allows for the construction of modular, transportable plants **110** that can be factory fabricated—further reducing their costs. The ability to provide for energy self sufficiency as discussed with reference to this embodiment allows transportable plants **110** based on this technology to operate in remote areas where biomass feedstocks are plentiful and lowest in cost. The distributed production of liquid fuel costs also reduces the need to transport low density, low value materials over long distances, further enhancing the economics of the process and, through aggregation of the products, can make large-scale bioenergy use feasible.

[0049] As those skilled in the art will certainly appreciate, fast pyrolysis thermochemical processes use heat in the absence of oxygen (typically in the range of 660° F. to 1020° F. (350° C. to 550° C.), depending on feedstock characteristics and other factors) to breakdown carbonaceous materials into gases (roughly 75% yield) and char (roughly 25% yield). The condensable gases (roughly 80% of the gases) are recovered as liquids after condensation leaving the non-condensable gases, which typically have an aggregated energy value in the range of 250 to 300 Btu/ft3. The char product can have energy values in the range of 12,000 Btu/lb.

[0050] The method of heating the contents of the fast pyrolysis reactor chamber **114** may vary widely but all fast pyrolysis processes require that the carbonaceous materials be heated to the desired process temperature in roughly 1 second. Heat is required for the fast pyrolysis reactions and, depending on feedstock input requirements and quality, for drying the feedstock. Electrical energy is required for process materials handling and control and, depending on design, other purposes.

[0051] The present invention allows one to complete the fast pyrolysis process in an energy self-sufficient (to the extent possible) manner, including facilitating the operation of transportable plants **110**, especially the operation of plants **110** in remote areas away from traditional infrastructure. Additionally, syngas is produced continuously as the fast pyrolysis process is operating and this gas is not readily compressible or storable. While traditional disposal of this gas by flaring complicates environmental permitting and wastes valuable energy, the present invention employs this syngas in an efficient and effective manner.

[0052] As briefly discussed above, the present invention integrates an engine-generator **190** into the fast pyrolysis process with heat recovery and electrical energy generation from the engine-generator **190** for providing both electrical and thermal energy required for operation and control of the present fast pyrolysis plant **110**. In accordance with a preferred embodiment, this engine-generator **190** is fueled with syngas or the liquid fuel product generated as a result of operation of the present process, or the fuels together. If necessary or desired, it is contemplated this engine-generator **190** could also use conventional fuels (e.g., diesel fuel). As used herein, this engine-generator **190** can be an external combustion engine or internal combustion engine (preferred embodiment) including reciprocating engines and combustion turbines and no limitation is placed on the type of heat engine, although some engines are better suited than others for this application. Electrical energy could also be generated through the use of thermopiles or other means and thermal energy recovered from these methods.

[0053] Since electricity is the most expensive form of energy required in the fast pyrolysis process, sound engineering design requires that the engine-generator **190** be sized to meet the process electrical requirements (although alternative design methods could be used). The method of design dictates the amount of waste heat available. Additionally, the type of prime mover (engine) dictates the form and quality of waste heat available. Heat is available from the engine-generator **190** in the form of hot air exhaust, hot radiator fluid or air from the radiator, and hot air from the crankcase engine oil cooler, if so equipped. As such, a radiator **192** and crankcase oil cooler **194** are linked to the engine-generator **190** (in accordance with a preferred embodiment, the radiator and oil cooler are integrated with the engine generator **190**) for extracting heat, which is subsequently used in supplying heat to the dryer **180** or other applications via supply lines **196**, **198**. For example, in a diesel engine heat can be recovered from the radiator in a liquid heat transfer medium such as a water/glycol solution (typical temperature 180° F. (82° C.) to 200° F. (93° C.)) or as hot air from the radiator (typical temperatures 80° F. (26° C.) to 130° F. (54° C.), depending on ambient conditions and other factors. Where the heat engine-generator uses an oil cooler, heat may be recovered from the hot oil with typical oil temperatures in the range of 250° F. (121° C.). Typical exhaust temperatures from a combustion turbine with a recuperator are 500° F. (260° C.) and without a recuperator, 900° F. (482° C.). Exhaust from a diesel reciprocating engine is typically in the range of 800° F. (427° C.) to 1200° F. (649° C.).

[0054] As discussed above, fast pyrolysis reactions require temperatures in the range of 660° F. to 1020° F. (350° C. to 550° C.), with some thermochemical gasification processes requiring even higher temperatures. For indirectly heated processes such as most fast pyrolysis processes, temperatures required for process heat transfer may be in the range of 1200° F. (649° C.) to 1600° F. (871° C.), more or less, depending on desired process operating temperatures, mode of heat transfer to the contents of the reactor, and other factors. Thus the temperatures provided by heat recovery from the engine-generator **190** alone are not high enough for indirectly heating fast pyrolysis reactors (for example, transferring heat to the heat carrier for the fast pyrolysis reaction) and, additionally, the heat recovered from the engine-generator **190** may not provide enough energy for both the fast pyrolysis reactor chamber **114** and associated process dryer **180** operations.

[0055] Therefore, the present invention employs the heat of the exhaust **199** from the engine-generator **190** by connecting it to the furnace **141** via tube **200**. After being directed to the furnace **141**, the heat of the exhaust **199** is passed into the heat exchanger **168** (connecting the char separation and recovery system **144** with the reactor chamber **114**) with the heat generated by the furnace **141** to boost the exhaust temperature to that desired for providing heat to the fast pyrolysis reaction and, if necessary, the additional energy required for the process operations or other purposes. As such, the heat for this heat exchanger **168** comes from both the furnace **141** and the engine-generator **190**; that is, the furnace **141** boosts in temperature heat generated by the engine-generator **190** and adds energy to the heat (that is, the exhaust **199**) generated by the engine-generator **190**. As discussed above, the furnace **141** can use syngas, bio-oil, or char from the process as fuels (the preferred embodiment) and may be supplemented if necessary or desired with other fuels. Additionally, this heat could come from a source external to the fast pyrolysis process, such as from a co-located process or heat source.

[0056] Another element incorporated into this embodiment involves the use of heat recovered from the heat carrier heat exchanger **168**. Temperature drops for the heat carrier through the heat carrier heat exchanger can range from 100° F. (38° C.) to 600° F. (316° C.), thus considerable thermal energy remains in the heat carrier (or heat transfer medium) after the fast pyrolysis reactor chamber **114** and can be recovered and used for drying the incoming feedstock to increase overall process efficiency by linking the heat carrier heat exchanger **168** with the dryer **180** via tubing **202** (see FIGS. **8** and **9**). Many feedstocks may have initial moisture contents in the range of 50% (wet basis) while good fast pyrolysis efficiencies typically require feedstock moisture contents in the range of 10% or less. Feedstock drying can be accomplished at temperatures as low as 250° F. (121° C.), thus thermal energy in the heat transfer medium from the fast pyrolysis reactor can be recovered and used either directly (the preferred embodiment) or indirectly as a thermal energy source for the dryer. Depending on initial feedstock moisture content and other factors, all of the energy required for drying the feedstock can be provided in this manner.

[0057] Depending on thermal energy requirements, additional thermal energy may also be recovered from the engine radiator **192** or oil cooler **194** and blended into the thermal energy stream from the heat carrier heat exchanger **168** into the dryer **180**, or used for other purposes. If the energy requirements of the dryer **180** are greater than the thermal energy recovered from the heat carrier heat exchanger **168**, some of the thermal energy generated by the engine-generator **190** and furnace **141** can bypass the heat carrier heat exchanger (via tube **204**) and go directly to the dryer **180** or another application. In some situations, air that is cooler, such as ambient air, may need to be added to the air inlet to the dryer to reduce the temperatures of the air from the heat transfer medium from the engine, furnace, or reactor. This description of possible energy flows is not meant to be exclusive and other combinations are possible.

[0058] Operating parameters for the present system are disclosed in detail in commonly owned U.S. patent application Ser. No. 11/480,914, filed Jul. 6, 2006, which was been published as U.S. Patent Application Publication No. 2008/0006519 on Jan. 10, 2008, entitled "METHOD AND SYSTEM FOR ACCOMPLISHING FLASH OR FAST PYROLYSIS WITH CARBONACEOUS MATERIALS", which is incorporated herein by reference.

[0059] While the preferred embodiments have been shown and described, it will be understood that there is no intent to limit the invention by such disclosure, but rather, is intended to cover all modifications and alternate constructions falling within the spirit and scope of the invention.

1. A pyrolysis system including a plant for use in the processing of bio-fuels, the plant comprising:
- a base frame including a first end and a second end, as well as a first lateral side and a second lateral side;
- an inlet shaped and dimensioned for the input of carbonaceous feedstock mounted to the base frame adjacent to the first end;
- a reactor chamber mounted to the base frame and coupled to the inlet by a feed mechanism which directs carbonaceous feedstock from the inlet to the reactor chamber;
- a condenser system positioned and supported along the first lateral side of the base frame by a vertical supporting framework;
- a char separation and recovery system mounted upon the base frame and coupled to the reactor chamber by a conveying mechanism for transporting char and heat carrier from the reactor chamber to the char separation and recovery system; wherein the char separation and recovery system is positioned so that its long axis is parallel to the long axis of the base frame; and
- a heat exchanger circulating the heat carrier from the char separation and recovery system back to the reactor chamber.

2. The pyrolysis system according to claim **1**, wherein the plant is shaped and dimensioned for placement within a container suitable for over-the-road transportation.

3. The pyrolysis system according to claim **2**, wherein the shipping container has a volume of approximately 3,648 cubic feet.

4. The pyrolysis system according to claim **1**, further including a dryer in communication with the inlet.

5. The pyrolysis system according to claim **1**, further including an engine-generator.

6. The pyrolysis system according to claim **5**, wherein the engine-generator supplies heat to the heat exchanger.

7. The pyrolysis system according to claim **5**, further including a dryer in communication with the inlet and wherein the engine generator supplies heat to the dryer.

8. The pyrolysis system according to claim **5**, wherein the engine-generator is fueled with syngas or the liquid fuel product generated as a result of operation of the present plant.

9. The pyrolysis system according to claim **5**, wherein a radiator is linked to the engine-generator and heat recovered from the engine radiator for use by the plant or other application.

10. The pyrolysis system according to claim **9**, wherein a crankcase oil cooler is linked to the engine-generator and heat recovered from the engine oil cooler for use by the plant or other application.

11. The pyrolysis system according to claim **5**, wherein a crankcase oil cooler is linked to the engine-generator and heat recovered from the engine oil cooler for use by the plant or other application.

12. The pyrolysis system according to claim **5**, further including a furnace, wherein the engine-generator supplies heat to the furnace and the furnace boosts in temperature the heat generated by the engine-generator.

13. A pyrolysis system including plant for use in the processing of bio-fuels, comprising:

a base frame including a first end and a second end, as well as a first lateral side and a second lateral side;

an inlet shaped and dimensioned for the input of carbonaceous feedstock mounted to the base frame adjacent to the first end with a dryer in communication with the input;

a reactor chamber mounted to the base frame and coupled to the inlet by a feed mechanism which directs carbonaceous feedstock from the inlet to the reactor chamber;

a condenser system positioned and supported along the first lateral side of the base frame by a vertical supporting framework;

a char separation and recovery system mounted upon the base frame and coupled to the reactor chamber by a conveying mechanism for transporting char and heat carrier from the reactor chamber to the char separation and recovery system;

a heat exchanger circulating the heat carrier from the char separation and recovery system back to the reactor chamber; and

an engine-generator linked to a furnace, wherein the engine-generator supplies heat to the furnace and the furnace boosts in temperature the heat generated by the engine-generator for use by the plant.

14. The plant according to claim **13**, wherein the engine-generator is fueled with syngas or the liquid fuel product generated as a result of operation of the present plant.

15. The plant according to claim **13**, wherein a radiator is linked to the engine-generator and heat recovered from the engine radiator for use by the plant or other application.

16. The plant according to claim **15**, wherein a crankcase oil cooler is linked to the engine-generator and heat recovered from the engine oil cooler for use by the plant or other application.

17. The plant according to claim **13**, wherein a crankcase oil cooler is linked to the engine-generator and heat recovered from the engine oil cooler for use by the plant or other application.

18. The plant according to claim **13**, wherein the engine-generator supplies heat to the heat exchanger.

19. The plant according to claim **13**, wherein the engine-generator supplies heat to the dryer.

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