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(54) **Title**: THERMAL TRANSFER MECHANISMS FOR AN AUGER PYROLYSIS REACTOR

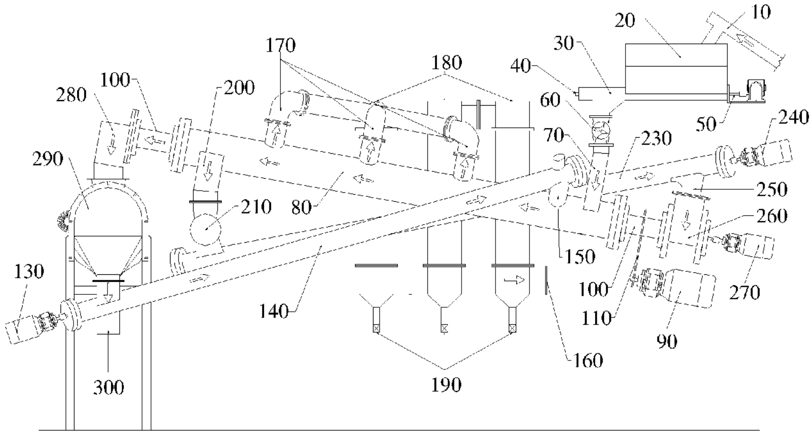

FIG 1.

(57) **Abstract**: An improved method of providing heat to a pyrolysis reactor is disclosed. A solid heat carrier produces fast pyrolysis vapors during transport of the solid heat carrier/feedstock mixture down the shell of the main reactor tube by the reactor tube auger. These vapors are drawn from the main reactor tube by a slight vacuum pressure and are condensed in a multiple condenser train comprised of shell and tube condensers cooled by water or other means.

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THERMAL TRANSFER MECHANISMS FOR AN AUGER PYROLYSIS REACTOR

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] None

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] This invention was made with Government support under DE-FG36-06GO86025 awarded by the U. S. Department of Energy. The Government has certain rights in the invention.

FIELD OF THE INVENTION

[0003] The present invention is generally directed toward a method of supplying heat for pyrolysis by a solid heat carrier.

BACKGROUND OF THE INVENTION

[0004] Fast pyrolysis produces a liquid product, known as pyrolysis oil or bio-oil. The required pyrolysis conditions for fast pyrolysis are a temperature of 400°C to 650°C and the absence of oxygen. This temperature range results in the decomposition of the biomass cell structures into their molecular components. At these moderate temperatures, a fraction of biomass is converted to approximately 10% to 15% syngas by pyrolysis, but the majority is converted to pyrolysis oil (60% to 70%) or char (15%). Bio-oil chemical properties vary with the feedstock, but woody biomass typically produces a mixture of 25% to 30% water, 30% phenolics, 20% aldehydes and ketones, 15% alcohols and 15% miscellaneous compounds.

[0005] Commercial pyrolysis reactors obtain most of the energy for their energy-intensive process from the by-products of bio-oil production. The 15% char and 10% syngas generated during pyrolysis are typically combusted to provide the heat energy required for pyrolysis and to dry biomass to below approximately 10% moisture content level needed for pyrolysis. Biomass moisture contents above approximately 10% will produce bio-oils containing prohibitively high water content values. The 10% biomass moisture content level results in 20%-30% total water production in the bio-oil. More than half of the water produced in bio-oil during pyrolysis is produced by combination of the oxygen and hydrogen molecules produced during biomass pyrolytic thermal decomposition. The exit gas resulting from pyrolysis is composed of CO_2, CO, methane and small amounts of hydrogen and oxygen. All but CO_2 are available to combust to produce heat, and this is the typical practice for providing additional energy for pyrolysis reactor heating.

[0006] Rapid decomposition of the biomass requires less than approximately two seconds residence time to produce maximum liquid yields. The rapidity of the thermal biomass decomposition results in the production of a condensate that is not at thermodynamic equilibrium at normal storage temperatures.

[0007] Maximization of liquid yields requires that all fast-pyrolysis reactors share the ability to heat feedstocks rapidly at very high heat transfer rates in order to maximize liquid yields. This rapid heating prevents undue thermal cracking of the biomass molecular vapors to non-condensable gas vapors. In addition, the highly reactive molecules produced in the initial pyrolysis stage will polymerize to char if the pyrolysis reaction is slower than optimum. While rapid heat transfer to produce maximum primary decomposition products is necessary, these products must be removed quickly from the pyrolysis zone to the reactor condensation process; again, this prevents over cracking of the primary vapors and polymerization of these materials to char. (Venderbosch, R.H. and W. Prins. 2010. Biofuels, Bioprod Bioref. 4:178-208.). Although heat transfer rates will vary, it has been estimated that rates greater than 500 W/m2K are required for good liquid yields from application of the fast pyrolysis process.

[0008] Previously known reactor types include the entrained down-flow, ablative, fluid bed, circulating fluid bed, transported bed, vacuum moving bed, auger and rotating cone reactors.

[0009] In practice, and particularly in scale up to industrial production, there are drawbacks to each of these designs that have precluded commercialization for all but Ensyn's entrained down-flow reactor. (Vandenbosch and Prins 2010).

[0010] Regardless of pyrolysis design drawbacks, those reactor designs that combine a small inert solid particulate heat carrier (usually sand) with relatively small particles of biomass (1 to 5 mm) obtain the best heat transfer rates. This is due to the intimate contact of the solid heat carrier (SHC) with the biomass, combined with the small size of the biomass particle which allows good thermodynamic heat transfer to, and within, the particle.

[0011] Auger reactors typically consist of a reactor tube within which an auger turns to move the feedstock through the tube. In early versions, only the external wall of the tube was heated. Heat was transferred to biomass particles by a combination of ablative heating from contact of the particles with hot interior tube surface and by conduction of heat radiating from the internal pipe surface to the feedstock particles. This means of heating biomass feedstock can be successful for very small-diameter reactor tubes which have limited distance between inner reactor tube surface and the internal auger shaft. The minimization of this distance can allow adequate heating transfer rates to achieve production of moderately high yields of bio-oil. However, production capacity is limited by the small tube diameter hampering scale up to industrial production. Larger tube diameters result in low heat transfer rates that require slow augering of the biomass through the tube. This results in slow pyrolysis with corresponding low liquid bio-oil yields.

[0012] Practitioners of the auger pyrolysis reactor design have attempted to solve the slow heating-rate issue in order to achieve fast pyrolysis by developing means to provide additional heat beyond that applied to the external surface of the auger tube in various ways, but none of them have been as successful as the method disclosed herein. These prior-art reactors have utilized, or suggested utilizing, a means to provide heat internal to the auger shaft in the form of hot air, fluids, electric or other heating medium that is not in the form of a SHC. However, the presently disclosed method utilizing still-hot SHC/char mixture produced by pyrolysis provides a much more efficient production and transfer of pyrolysis heat.

SUMMARY OF THE INVENTION

[0013] It is the object of the present invention to provide a source of pyrolysis heat carried by a SHC by using the hot SHC/char mixture produced during pyrolysis in the shell of an auger reactor for pyrolysis heat. Following the pyrolysis of the biomass feedstock in the main reactor tube, the mixture of hot SHC and char remains at high temperature. By our method, this hot SHC/char mixture is fed into the hollow shaft of the main auger reactor shaft to heat the auger shaft internally by conduction. This conducted heat is transferred from the internal surface of the internal auger tube to the external surface and is subsequently transferred, via both conduction and convection, to the SHC/feedstock mixture fed by the auger through the main reactor tube (MRT) shell. Auger reactor tubes for transport of the SHC/char mixture from the outlet of the MRT shell may be heated externally by any means to prevent cooling so as to maintain adequate pyrolysis heat prior to the introduction of the mixture into the hollow auger shaft. It is also an object of the present inventions to produce torrefied wood by our method of utilizing the SHC/char mixture to heat the auger shaft internally. Production of torrefied wood required application of a pyrolysis temperature of approximately one-half of that required to produce maximum yields of bio-oil via fast pyrolysis. However, aside from the temperature difference, and the fact that the product is torrefied wood rather than bio-oil and char, the operating principles of the reactor are identical to those for application of fast pyrolysis.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Further advantages of the invention will become apparent by reference to the detailed description of preferred embodiments when considered in conjunction with the drawings:

[0015] FIG. **1** depicts a frontal view of the auger pyrolysis reactor.

[0016] FIG. **2** depicts a top view of the auger pyrolysis reactor.

[0017] FIG. **3** depicts double cutaway side views of the MRT showing both the main reactor tube auger view and the main reactor tube internal auger.

[0018] FIG. **4** depicts a cross-sectional view of the MRT showing the internal tube structure and augers.

DETAILED DESCRIPTION

[0019] The following detailed description is presented to enable any person skilled in the art to make and use the invention. For purposes of explanation, specific details are set forth to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that these specific details are not required to practice the invention. Descriptions of specific applications are provided only as representative examples. Various modifications to the preferred embodiments will be readily apparent to one skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the scope of the invention. The present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest possible scope consistent with the principles and features disclosed herein.

[0020] The preferred embodiment of the current invention is to utilize the SHC to provide pyrolysis heat in the shell of the auger reactor. For this purpose, the SHC is introduced into the auger reactor following, before, or with the entry of the feedstock into the MRT shell. The SHC should be heated to an effective temperature to achieve fast pyrolysis when mixed with the feedstock in the main reactor tube shell. The preferred temperature of the SHC upon entry into the main reactor tube shell is approximately 500°C but may range between 100°C to 300°C for the production of torrefied wood and between 300°C to 650°C for pyrolysis to produce bio-oil.

[0021] The heated SHC produces fast pyrolysis vapors during transport of the SHC/feedstock mixture down the shell of the main reactor tube by the reactor tube auger. These vapors exit the MRT propelled by the slight positive pressure produced by the pyrolysis reaction. Alternatively, the vapor speed exit velocity may be increased by application of a slight vacuum pressure at the exhaust flue. Regardless of the speed of vapors evacuation, they are condensed in a multiple condenser train comprised of shell and tube condensers cooled by water or other means. When the reactor is applied to torrefy the feedstock, it may not be advantageous to produce a liquid product. In this case, the vapors produced may be allowed to immediately exit the reactor without the need for a condenser system.

[0022] Following pyrolysis of the feedstock in the MRT, the hot SHC/char mixture produced is transported and input into the hollow shaft of the MRT auger. A second auger inside this hollow shaft transports the SHC/char mixture through the auger shaft. The heat from the mixture produces internal heat that is transferred via conduction to the auger tube wall and, subsequently, to the SHC/feedstock mixture moving through the shell of the MRT.

[0023] Additional heat may be supplied internal to the auger shaft by any means other than the SHC/char mixture. This additional heat may be supplied in any form: hot fluid, hot air, electrical, microwave, infrared, or other. During travel of the SHC or the SHC/char mixture, the preferred embodiment of the present invention will provide heat external to the auger tubes transporting the mixture to provide for maintenance of the temperature required for adequate pyrolysis.. The heat required for the maintenance of the SHC/char mixture during transport may be produced by any means: hot fluid, hot air, electrical, microwave, infrared, or other. Additional pyrolysis heat may be supplied to a second shell outside the MRT shell which carries the feedstock mixture. This heat may be provided in any form: hot fluid, hot air, electrical, microwave, infrared, SHC or other.

[0024] The SHC/char mixture may be substituted by any other SHC and still maintain the novelty of the present invention.

[0025] The feedstock pyrolyzed by the current invention may be any pyrolyzable material such as biomass, coal, rubber, oil shale or other.

[0026] For the application of fast pyrolysis to produce bio-oil, the SHC may be heated by char combusted in a char furnace of any design. Further, a heat exchange system of any design may be applied to transfer heat optimally to the SHC when utilized in conjunction with a char furnace. For torrefaction, the char, or torrefied wood product, is the marketable product, rather than the bio-oil produced by fast pyrolysis. Because the torrefied wood will be sold, it will not be available to combust to produce energy for the pyrolysis process. Therefore, when the auger reactor of the current invention is applied to produce torrefied wood, the heat supplied to the SHC must be provided from other sources such as biomass, gas, diesel, bio-oil, electrical or other.

[0027] As can be appreciated from the drawings, particulate feedstock of any type is delivered to a feed stock hopper 20 by any means, but preferably by an auger tube or conveyor 10. The feedstock is fed into the reactor by any means from the feedstock hopper 20. Preferably, the feedstock hopper is sealed to exclude air, but the hopper may be open to the atmosphere. Feedstock may be transferred from the feedstock hopper by a horizontal auger tube 30, but any other means may also be used. Air may be excluded from the feedstock hopper by means of purging the air incorporated with the feedstock by introduction of nitrogen, or any other inert gas, fed at any location on the feedstock hopper or at a location downstream from the feedstock hopper. Preferably, the nitrogen for purging the feedstock enters the reactor just above the rotary valve 40 to allow purging of the air from the feedstock prior to its entry into the MRT. The nitrogen feed rate may be of any magnitude, but is preferably restricted to the minimum nitrogen pressure required to prevent air from entering the feedstock hopper. The feedstock hopper may utilize an auger 50 to deliver feedstock to a rotary valve 60. The rotary valve 60 delivers feedstock through the feedstock inlet 70 into the MRT shell 310. The term shell, as utilized here, means the open area inside the MRT inner surface and the outer surface of the auger shaft internal to the main auger tube. The MRT outer surface is shown as 80.

[0028] The feed works mechanism may be a rotary valve of any type such that it serves to exclude air from the MRT shell. Any type of feeding device that effectively delivers feedstock to the MRT, while excluding air, may be substituted for the rotary valve. The MRT shell 310 houses the MRT auger 100 that transports the feedstock, utilizing external flights, during its pyrolysis in the MRT shell. The auger motor 90 turns the MRT auger shaft 100. The preferred embodiment for transferring rotary motion from the auger shaft motor to the auger is a chain drive 110, but may be any suitable device to serve this purpose. The MRT auger 100 is a tube externally fitted with auger flights that are utilized to transport the SHC/feedstock mixture through the MRT shell.. A tube is required to provide a hollow shaft for the MRT auger such that the SHC/char mixture can subsequently be passed through it. FIGs 3 and 4 show a view of the hollow shaft 320 of the MRT auger. This hollow shaft allows an internal auger 330 to transport the SHC/char (to be defined below) mixture through the MRT auger shaft. The SHC/char mixture provides a second source of heat internal to the main auger tube, in addition to the heated SHC mixed with the initial feedstock, to provide pyrolysis heat.

[0029] For pyrolysis, the preferred method to heat the SHC is a char furnace 120, of any design, fueled by combusted char produced by the pyrolysis reactor. Electric ring heaters, electric furnaces or other means to heat the SHC in a device separate from the pyrolysis reactor or as a component of the reactor may be substituted for the char furnace. The SHC is transferred via auger motor 130 inside the SHC delivery tube 140 to the SHC MRT inlet 150.

[0030] The MRT 80, SHC delivery tube 140, SHC/char transfer pipe 210 and SHC/char return pipe 230 will preferably be supplied with supplemental heat to maintain SHC temperature during transport. This heat may be applied to the MRT tube or SHC delivery tube by any means. The preferred method is to input hot gases from the char furnace into such jackets. As an example, the optional MRT jacket for supplying the supplemental heat to the MRT 340 is shown in FIGs 3 and 4. The jackets for supplemental heating to the SHC delivery tube 140, SHC/char transfer pipe 210 and SHC/char return pipe 230 are not shown, but it is understood that they are of similar design to that shown for the MRT 340 in Figs 3 and 4.

[0031] The preferred embodiment of the SHC is spherical steel shot of any suitable diameter for optimum passage of the SHC/feedstock combination through the MRT. The optimum diameter of the SHC will be determined by heat transfer considerations. The SHC may be composed of any suitable material that will maintain its shape and effectively transfer heat to the feedstock to ensure its reaching pyrolysis temperature. The preferred pyrolysis temperature is 450°C but may be any reasonable pyrolysis temperature ranging from approximately 300°C to 650°C. The preferred embodiment for proportion of SHC utilized in relation to biomass volume is 50% of the volume of space occupied by the feedstock fed through the reactor. However, this proportion must be determined by experiment and will vary with the size of the pyrolyzer. The SHC may also be composed entirely or partially of a material that acts as a catalyst during pyrolysis. The SHC may also be composed of catalytic material, or have a catalyst incorporated in any proportion into the material comprising it for this purpose. The catalytically active SHC may preferably be utilized to partially, or completely, deoxygenate the biomass, biomass vapors and resultant bio-oil produced during pyrolysis. In addition, an SHC comprised completely, or partially, of a catalytic material may be utilized to perform any type of upgrading of the biomass, biomass vapors and resultant bio-oil.

[0032] As previously stated, the SHC is introduced into the MRT 80 through the SHC MRT inlet 150. The SHC drops into the MRT shell 110 to be mixed with the feedstock already introduced into the reactor and fed by the MRT auger shaft 100. The optimum speed of the auger shaft, to accomplish optimum fast pyrolysis of the transported feedstock, must be determined by experiment and will depend on feedstock type, particle size, SHC diameter and size of the MRT 80, etc. The heat transferred to the feedstock by the SHC during its travel down the MRT shell is one source of heat to accomplish fast pyrolysis with the current invention.

[0033] Our preferred method to move vapors from the MRT pyrolysis reaction zone is to apply a slight vacuum pressure at the exit gas flue pipe 160. This vacuum pressure can also be applied by any other means. The optimum amount of vapor pressure must be determined by experiment so as to remove pyrolysis vapors to achieve a fast pyrolysis vapor residence time. This vapor residence time may be variable but should be less than 0.2 second which is considered the maximum time for effective fast pyrolysis. The vapors will preferably be drawn from the MRT 80 at three port locations 170, but there may be any number of port locations. Multiple ports allow vapors to be drawn from the MRT for transmission to the condenser train 180 by the shortest path and in the shortest possible time. This reduces the vapor residence time ensuring that over pyrolysis does not occur, such that bio-oil quality is reduced.

[0034] The condenser train 180 consists of three shell-and-tube condensers. However, the actual design may be of any type, and the number of condensers may be any number greater than, or equal to, one. For torrefaction, the number of condensers may be zero as the production of a liquid product may not be a desirable objective. The preferred condenser cooling means is by water but air cooling or cooling by any other means is possible. A water chiller (not shown) is utilized in the preferred embodiment of this device to allow continuous circulation of the same water for condenser cooling. Condensed pyrolysis oil that collects in the bottom of the condensers is drawn off by opening a valve 190 at the bottom of each condenser. However, any means for removing pyrolysis oil from the condensers may be utilized. The non-condensable gases produced during pyrolysis and that flow out of the condensers will exit the reactor through the exit gas flue 160.

[0035] Following the removal of pyrolysis vapors from the reactor tube, char remains mixed with the SHC, and this combined aggregate is termed the SHC/char mixture. This SHC/char mixture is transported to the SHC/char MRT outlet tube 200. The SHC/char mixture falls through the MRT outlet tube and into the SHC/char transfer pipe 210. From FIG. 2, it can be seen that the transfer pipe is an auger tube with the auger driven by the SHC/char transfer pipe motor 220. The SHC/char transfer pipe transports the SHC/char mixture to the SHC/char return pipe 230. The SHC/char mixture is transported by an auger driven by the SHC/char return pipe motor 240 to the internal auger inlet 250. The SHC/char mixture drops through this inlet into the SHC/char internal auger inlet hopper 260. The hopper collects the SHC/char mixture that is, then, transferred by the SHC/char internal auger motor 270 into the hollow interior of the MRT auger shaft 100.

[0036] The preferred embodiment of the current invention is to heat the internal auger shaft with the SHC/char mixture. It is to be understood, however, that the SHC could be separated from the SHC/char mixture and used alone for this heating purpose. Likewise, the char mixture could also be separated from the SHC/char mixture and utilized alone as the heat carrier to heat the internal auger shaft. Further, any proportion of either SHC or char could be removed, or an additional heat carrier in the form of air, fluids, solids, etc., could be added to provide additional heat sources to supplement the heat of the preferred SHC/char mixture heat carrier without departing from the novelty of the current invention.

[0037] The SHC/char mixture exits the MRT auger shaft at the SHC/char internal auger outlet 280. The SHC/char mixture drops into the SHC/char separator 290. This separator may be of any design suited to removing solids from a solids/char mixture. The preferred embodiment of the current invention utilizes a rotary screening device employing screens to separate the SHC from the char. The separated SHC drops into the previously described SHC delivery tube 140. The char exits the SHC/char separator system at the char outlet 300. The char can be collected at this point and utilized for any purpose. In our preferred embodiment, it is transferred to the char furnace 120 and is combusted to heat the SHC. However, for production of torrefied wood, the torrefied wood is the product to be sold. For this reason, the torrefied wood will be transferred to be prepared for shipping, rather than transported to the char furnace for combustion. Alternatively, the SHC/char mixture can be allowed to combust in any type of a combustion chamber to directly heat the SHC. The heated SHC can, then, be fed into the MRT with, or without, the removal of the ash resulting from this combustion.

[0038] The terms "comprising," "including," and "having," as used in the claims and specification herein, shall be considered as indicating an open group that may include other elements not specified. The terms "a," "an," and the singular forms of words shall be taken to include the plural form of the same words, such that the terms mean that one or more of something is provided. The term "one" or "single" may be used to indicate that one and only one of something is intended. Similarly, other specific integer values, such as "two," may be used when a specific number of things is intended. The terms "preferably," "preferred," "prefer," "optionally," "may," and similar terms are used to indicate that an item, condition or step being referred to is an optional (not required) feature of the invention.

[0039] The invention has been described with reference to various specific and preferred embodiments and techniques. However, it should be understood that many variations and modifications may be made while remaining within the spirit and scope of the invention. It will be apparent to one of ordinary skill in the art that methods, devices, device elements, materials, procedures and techniques other than those specifically described herein can be applied to the practice of the invention as broadly disclosed herein without resort to undue experimentation. All art-known functional equivalents of methods, devices, device elements, materials, procedures and techniques described herein are intended to be encompassed by this invention. Whenever a range is disclosed, all subranges and individual values are intended to be encompassed. This invention is not to be limited by the embodiments disclosed, including any shown in the drawings or exemplified in the specification, which are given by way of example and not of limitation.

[0040] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

[0041] All references throughout this application, for example patent documents including issued or granted patents or equivalents, patent application publications, and non-patent literature documents or other source material, are hereby incorporated by reference herein in their entireties, as though individually incorporated by reference, to the extent each reference is at least partially not inconsistent with the disclosure in the present application (for example, a reference that is partially inconsistent is incorporated by reference except for the partially inconsistent portion of the reference).

CLAIMS:

We Claim:

1. A method to supply heat for pyrolysis by a solid heat carrier.
2. The method of claim 1 wherein the solid heat carrier is char produced during the pyrolysis process.
3. The method of claim 1 wherein the solid heat carrier is a mixture, in any proportion, of char and a solid heat carrier of any size, shape or density.
4. The method of claim 1 wherein the solid heat carrier is heated in any manner to an appropriate temperature useful for pyrolysis of a pyrolyzable material.
5. The method of claim 1 wherein the solid heat carrier is heated by any means selected from the list consisting of microwave, infrared, hot fluid, air, and electric heater.
6. The method of claim 1 wherein the char is produced by the pyrolysis process and retains heat produced during pyrolysis.
7. The method of claim 1 wherein the solid heat carrier is introduced to a shell of the main reactor tube in which a pyrolyzable material and solid heat carrier are mixed in any proportion in order to cause pyrolysis of the pyrolyzable material.
8. The method of claim 1 wherein the solid heat carrier and char mixture is acquired as a byproduct from the reactor tube and introduced to an infeed of the hollow shaft of the main reactor tube.

9. The method of claim 1 wherein the solid heat carrier and char mixture is separated into the solid heat carrier and char as distinguished from the char or other byproducts of the pyrolysis process and char components with either being passed through the hollow shaft of an auger reactor to provide pyrolysis heat.
10. The method of claim 1 wherein the solid heat carrier or solid heat carrier/char mixture is transported to an infeed port to the hollow shaft of the main reactor.
11. The method of claim 10 wherein:

a. said transportation means is heated by any means to maintain, or increase, the temperature of the transported solid heat carrier or solid heat carrier and char; and

b. said hollow shaft containing an internal auger or any other means for transporting the solid heat carrier or solid heat carrier/char mixture.

12. The method of claim 11 wherein the solid heat carrier, solid heat carrier and char mixture, char, or torrefied biomass is transported inside the hollow internal auger shaft so as to contact the shaft's internal surface to allow for conducting of heat from the solid heat carrier to the internal auger shaft surface.
13. The method of claim 11 wherein the solid heat carrier, solid heat carrier and char mixture, char, and torrefied biomass are transported at a speed to promote heat transfer from internal auger shaft surface, through the material comprising the auger shaft, and to the outer surface of the internal auger shaft.

14. The method of claim 11 wherein the outer surface of the internal auger shaft comprises the internal surface of the shell of the main auger tube wherein:

a. the internal surface of the main auger shaft conducts heat to the pyrolyzable material and solid heat carrier being transported through the shell of the main auger tube during pyrolysis, and

b. the heat is conducted to the pyrolyzable material and solid heat carrier so as to increase the pyrolysis efficiency of the reactor.

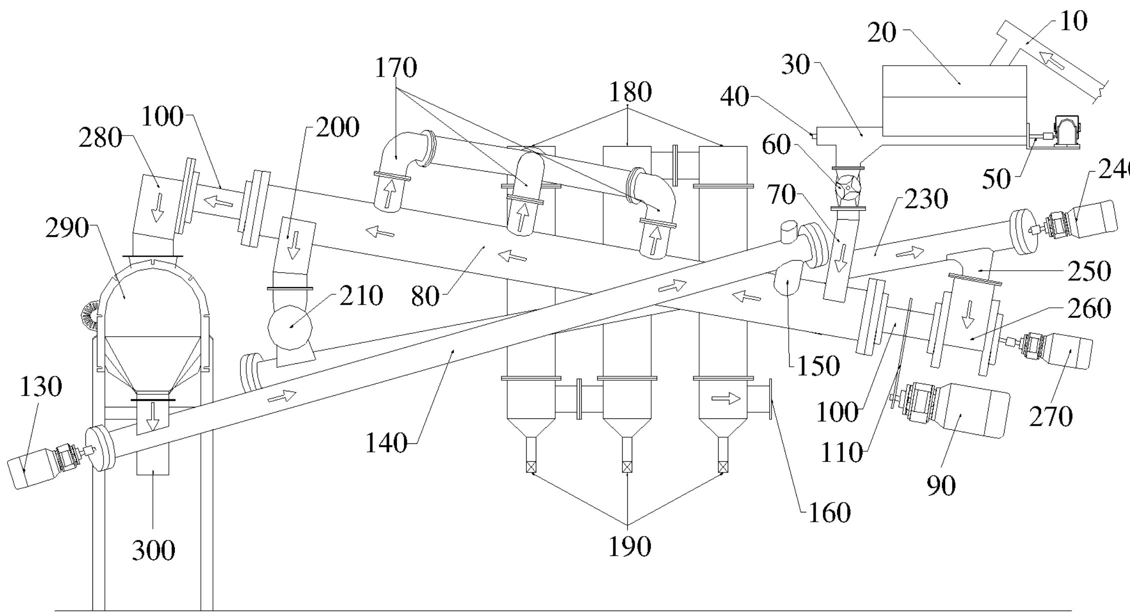
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FIG 1.

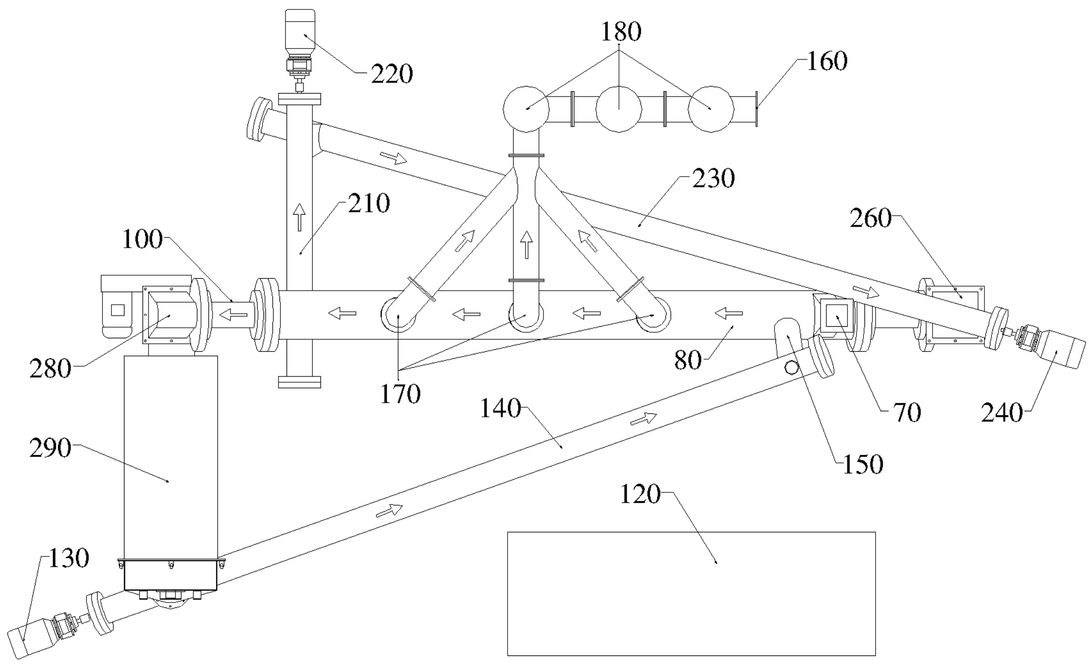
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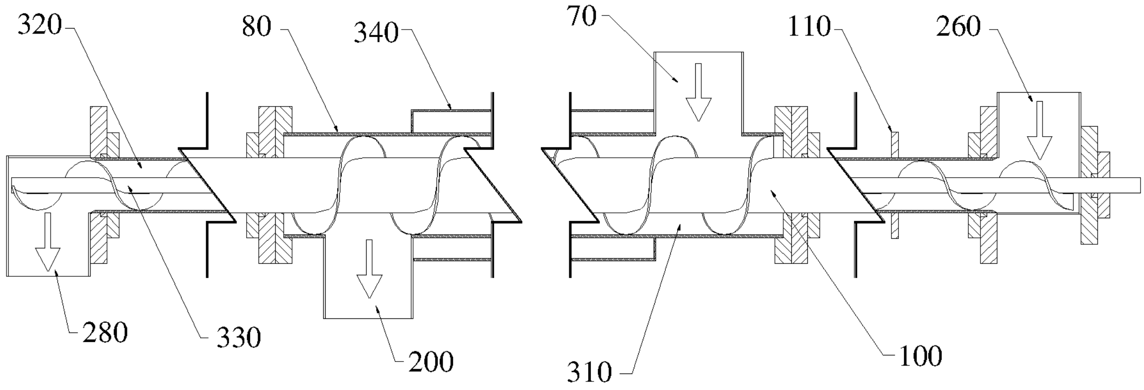
FIG. 2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100

FIG. 3

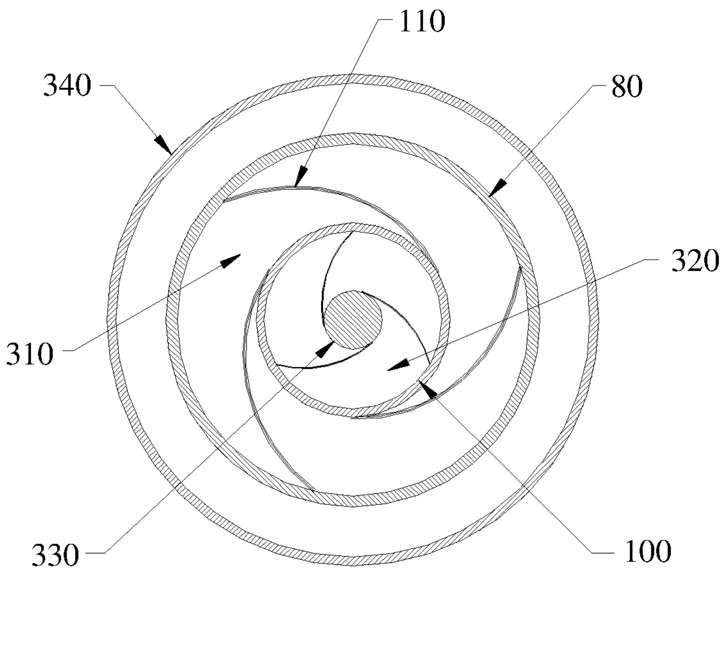
110
340
80
320
310
330
100

FIG. 4