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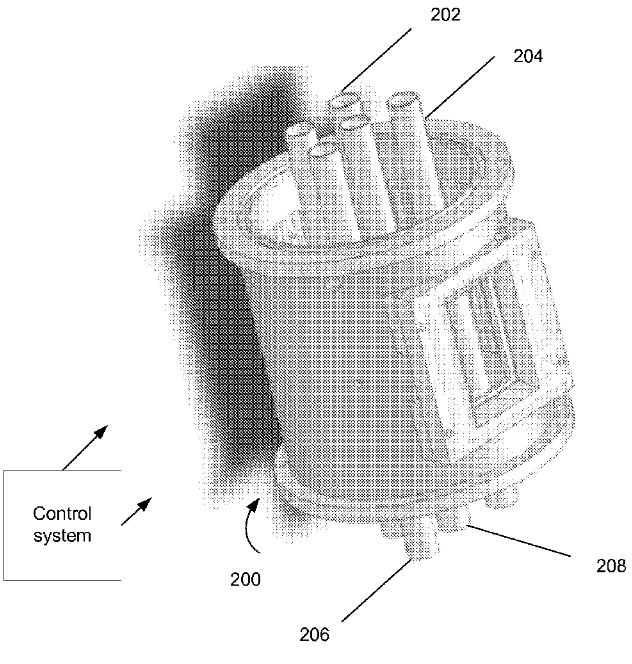
(54) Title: SYSTEMS AND METHODS FOR REACTOR AND RECEIVER CONTROL OF FLUX PROFILE



Multiple tube reactor

FIG. 2

(57) Abstract: A method, apparatus, and system for a solar-driven chemical reactor are disclosed, including a solar thermal receiver aligned to absorb concentrated solar energy. Some embodiments include a solar driven chemical reactor that has multiple reactor tubes. Some embodiments include one of 1) one or more apertures open to an atmosphere of the Earth or 2) one or more windows, to pass the concentrated solar energy into the solar thermal receiver. This energy impinges on the multiple reactor tubes and cavity walls of the receiver and transfer energy by solar radiation absorption and heat radiation, convection, and conduction. In this way, the energy causes reacting particles to drive the endothermic chemical reaction flowing in the reactor tubes. The design of the multiple reactor tubes and solar thermal receiver can be adapted per a solar flux profile to take advantage of variations in the concentrations of solar flux in the profile.

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SYSTEMS AND METHODS FOR REACTOR AND RECEIVER CONTROL OF FLUX PROFILE

RELATED APPLICATIONS

[001] This application claims the benefit of both U.S. Provisional Patent Application Serial No. 61/248,282, filed October 2, 2009 and entitled "Various Methods and Apparatuses for Sun Driven Processes," and U.S. Provisional Patent Application Serial No 61/185,492, titled "VARIOUS METHODS AND APPARATUSES FOR SOLAR-THERMAL GASIFICATION OF BIOMASS TO PRODUCE SYNTHESIS GAS" filed June 9, 2009.

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FIELD OF THE INVENTION

[003] Embodiments of the invention generally relate to systems, methods, and apparatus for refining biomass and other materials. More particularly, an aspect of an embodiment of the invention relates to solar-driven systems, methods, and apparatus for refining biomass and other materials.

BACKGROUND OF THE INVENTION

[004] The substance/substances initially involved in a chemical reaction are generally called reactants. Chemical reactions are usually characterized by a chemical change in the reactants, which then yields one or more products. Biomass gasification is an endothermic process; energy must be put into the process to drive it forward. Typically, this is performed by partially oxidizing (burning) the biomass itself. Between 30% and 40% of the biomass must be consumed to drive the process, and at the temperatures which the process is generally limited to (for efficiency reasons), conversion is typically limited, giving still lower yields. Also, the chemical reactors in such traditional biorefineries are generally engineered to operate at constant conditions around the clock. In contrast, the proposed solar-driven chemical refinery uses an external source of energy (solar) to provide the energy required for reaction, so none of the biomass need be consumed to achieve the conversion. This results in significantly higher yields of gallons of gasoline per biomass ton than previous technologies. As such, the energy source being used to drive the conversion is renewable and carbon free.

SUMMARY OF THE INVENTION

[005] Some embodiments relate to a method, apparatus, or system for a solar-driven chemical reactor. An example system may include a solar thermal receiver aligned to absorb concentrated solar energy from one or more solar energy concentrating fields including 1) an array of heliostats, 2) solar concentrating dishes, and 3) any combination of the two. Some embodiments include a solar driven chemical reactor that has multiple reactor tubes located inside the solar thermal receiver. The endothermic chemical reaction in the multiple reactor tubes is driven by radiant heat. Additionally, the multiple reactor tubes in this reactor design increase available reactor surface area for radiative exchange to the reactants as well as create an inter-tube radiation exchange. Additionally, the endothermic chemical reaction can include one of the following biomass gasification, steam methane reforming, methane cracking, steam ethane cracking to produce ethylene, metals refining, carbon dioxide splitting, decomposition of certain hazardous materials and other similar endothermic carbon-based chemical reactions to be conducted in this reactor using solar thermal energy.

[006] Some embodiments include one or more apertures in the receiver 1) open to an atmosphere of the Earth or 2) with a window covering the aperture, to pass the concentrated solar energy into the solar thermal receiver. This energy impinges on the multiple reactor tubes and cavity walls of the receiver and transfer energy by solar radiation absorption and heat radiation, convection, and conduction. In this way, the energy transmitted to the reactants in the chemical reaction drives the endothermic chemical reaction flowing in the reactor tubes. The design of the multiple reactor tubes and solar thermal receiver can be adapted per a solar flux profile to take advantage of variations in the concentrations of solar flux in the solar flux profile including adapting 1) an amount of reactor tubes present in the cavity of the solar thermal receiver, 2) a size diameter of each of the reactor tubes in which a first reactor tube has a different diameter than a second reactor tube, 3) a geometric arrangement of a shape pattern of the multiple reactor tubes relative to each other, 4) a shape of each individual reactor tube may vary with respect to other tubes per the flux profile to take advantage of variations in solar flux in the profile and 5) a size, shape, and orientation of the apertures or windows relative to the concentrated solar energy coming from the array of heliostats or solar concentrating dishes.

BRIEF DESCRIPTION OF THE DRAWINGS

[007] The drawings refer to embodiments of the invention in which:

figure 1 illustrates a block diagram of an embodiment of an example process flow;

figure 2 illustrates a diagram of an embodiment of an example multiple tube reactor;

figure 3 illustrates a diagram of an embodiment of an example solar tower with receivers and heliostat field;

figure 4 illustrates a graph of an embodiment of particle size distribution;

figure 5 illustrates a diagram of an embodiment of a solar thermal receiver with gasifier tubes;

figures 6a and 6b illustrate block diagrams of embodiments of the entrained-flow biomass feed system;

figure 7 illustrates a diagram of an embodiment of a solar-driven chemical refinery; and

figure 8 illustrates a flow diagram of an embodiment of the system.

[008] While the invention is subject to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and will herein be described in detail. The invention should be understood to not be limited to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention.

DETAILED DISCUSSION

[009] In the following description, numerous specific details are set forth, such as examples of specific data signals, named components, connections, number of reactor tubes, etc., in order to provide a thorough understanding of the present invention. It will be apparent, however, to one of ordinary skill in the art that the present invention may be practiced without these specific details. In other instances, well known components or methods have not been described in detail but rather in a block diagram in order to avoid unnecessarily obscuring the present invention. Further specific numeric references such as first reactor tube, may be made. However, the specific numeric reference should not be interpreted as a literal sequential order but rather interpreted that the first reactor tube is different than a second reactor tube. Thus, the specific details set forth are merely exemplary. The specific details may be varied from and still be contemplated to be within the spirit and scope of the present invention. Features found in one embodiment may generally be used in another embodiment. The term coupled is defined as meaning connected either directly to the component or indirectly to the component through another component.

[0010] In general, a method, apparatus, and system for a solar-driven chemical reactor system can include a solar thermal receiver aligned to absorb concentrated solar energy from one or more solar energy concentrating fields including 1) an array of heliostats, 2) solar concentrating dishes, and 3) any combination of the two. Some embodiments include a solar driven chemical reactor that has multiple reactor tubes located inside the solar thermal receiver. In the multiple reactor tubes an endothermic chemical reaction driven by radiant heat occurs. Additionally, the multiple reactor tubes in this reactor design increase available reactor surface area for radiative exchange to the reactants as well as create an inter-tube radiation exchange. Additionally, the endothermic chemical reaction including one or more of the following: biomass gasification, steam methane reforming, methane cracking, steam ethane cracking to produce ethylene, metals refining, carbon dioxide splitting, decomposition of certain hazardous materials, and other similar endothermic carbon-based chemical reactions can be conducted in this reactor using solar thermal energy.

[0011] Some embodiments include one of one or more apertures 1) open to an atmosphere of the Earth or 2) with windows, to pass the concentrated solar energy into the solar thermal receiver. This energy impinges on the multiple reactor tubes and cavity walls of the receiver and transfer energy by absorption and re-radiation, convection, and conduction. In this way, the energy causes reacting particles to drive the endothermic chemical reaction flowing in the reactor tubes. The design of the multiple reactor tubes and solar thermal receiver can be adapted per a solar flux profile to take advantage of variations in the concentrations of solar flux in the profile including adapting 1) an amount of the at least two or more reactor tubes present in the cavity of the solar thermal receiver, 2) a size diameter of each of the reactor tubes in which a first reactor tube has a different diameter than a second reactor tube, 3) a geometric arrangement of a shape pattern of the multiple reactor tubes relative to each other, 4) a shape of each individual reactor tube may vary with respect to other tubes per the flux profile to take advantage of variations in solar flux in the profile and 5) a size, shape, and orientation of the apertures or windows relative to the concentrated solar energy coming from the array of heliostats or solar concentrating dishes.

[0012] In some embodiments, a solar-driven chemical reactor system may include a receiver that has two or more zones in which the reactor tubes and the receiver cavity in each zone are made out of different material. Different materials may be used to adapt to the amount of solar flux in that zone, peak temperature of that zone, or corrosion/steam conditions in that zone.

[0013] Additionally, a solar-driven chemical reactor system may include a non-uniform heliostat field. Such a field may have, for example, >25,000 m2 of reflecting surface. This reflecting surface can cooperate with the solar thermal receiver to have an ability to control an amount of solar energy flux across the apertures or windows that is applied to reactor tubes and cavity walls. Accordingly, this can allow enough energy from the radiant energy to raise the heat to initiate and sustain a sufficiently high temperature so that the gasification occurs of greater than 90 percent of the biomass particles into reactant products.

[0014] Figure 1 illustrates a block diagram of an example process flow. Some embodiments encompass a solar-driven-biomass gasification to liquid fuel/electrical process. The process might also include electrical generation, chemical processing, or bio-char, for solar generated syngas derivative product or other similar technical process. In a specific example implementation the process described is a solar-driven-biomass gasification to ‘green’ liquid fuel process. In an embodiment, this process includes one or more of the following process steps.

[0015] Biomass grinding or densification, transport, and then offload 100 may be part of the overall process. Bales of the biomass can be compressed and densified by a compactor to facilitate transport to on-site via the densification achieved by the compression and the bales are sized to dimensions that may, for example, fit within a standard boxcar size or shipping container size to fit within standard compactor size. The entrained-flow biomass feed system can be preceded by a grinding system equipped with mechanical cutting device and a particle classifier, such as a perforated screen or a cyclone, to control the size of the particles that are. The grinding system that has a mechanical cutting device such as a screw and set of filters with micron sized holes/screen diameter sized holes to control particle size. The biomass may be in an embodiment non-food stock biomass. In some cases, food stock biomass might also be processed.

[0016] The biomass may then be stored 102. As needed, the biomass might be fed 104 into an example system or apparatus of the instant application. For example, after grinding and pulverizing the biomass to particles, the particles of biomass can be fed into and gasified in the solar-driven chemical reactor. An entrained gas biomass feed system uses an entrainment carrier gas to move a variety of biomass sources fed as particles into the solar driven chemical reactor. Two or more feed lines supply the particles of biomass having an average smallest dimension size between 50 microns (um) and 2000 um to the chemical reactor.

[0017] A solar receiver and gasifier 106 may be used to break down the biomass. An example biomass gasifier design and operation can include a solar chemical reactor and solar receiver to generate components of syngas. The amount, size, and material of the reactor tubes in the gasifier 106 may be adapted per the flux profile to take advantage of variations in solar flux in the profile. Various heliostat field designs and operations to drive the biomass gasifier might be used. Some example systems may include a solar concentrator, secondary concentrator, focused mirror array, etc. to drive biomass gasifier 110.

[0018] Quenching, gas clean up, and ash removal from biomass gasifier 108 may be provided for. Some non-pilot syngas may exit the system 112. Some gasses may be a waste product, while other gasses can be compressed 114 prior to e.g. storage 118 or methanol synthesis 116. Methanol may then be stored 120 for later use or methanol to gasoline conversion 122.

[0019] In various embodiments, synthesis gas may be fed to another technical application. Examples include a syngas to other chemical conversion process. The other chemical or chemicals produced can include liquefied fuels such as transportation liquefied fuels. In an example, hydrocarbon based fuel methanol 116 may be formed from syngas. The methanol may be further processed to gasoline or other fuels 122 and various products may be separated out from the gasoline 124 or syngas. These products, e.g., gasoline, may be stored for later use as an energy source. Thus, an on-site chemical synthesis reactor may be geographically located on the same site as the syngas chemical reactor and integrated to receive the hydrogen and carbon monoxide products from the gasification reaction. This on-site chemical synthesis reactor has an input to receive the hydrogen and carbon monoxide products in a hydrocarbon fuel synthesis process performed in the on-site chemical synthesis reactor to create hydrocarbon fuels and/or chemicals. In an embodiment, the on-site chemical synthesis reactor is an on-site fuel synthesis reactor that creates liquid hydrocarbon fuels.

[0020] Figure 2 illustrates a diagram of an example multiple tube chemical reactor 200 that may be used in a solar driven system. Reactor 200 has multiple reactor tubes 202, 204, 206, 208. A separate feed/entrainment line may be used for each of the gasifier reactor tubes 202, 204, 206, 208 in the chemical reactor 200. This may allow for independent temperature control and balancing of amount of particles of biomass or other gases flowing in each of the reactor tubes 202, 204, 206, 208 in the multiple tube solar driven chemical reactor 200. The particles of biomass feed can be distributed to the reactor tubes 202, 204, 206, 208 by a lock hopper rotary feed system, such as a Rotofeed® lock hopper rotary feed system. Such a system can allow for balanced feeding to individual reactor tubes 202, 204, 206, 208 and feed rate of the particles is controlled by a weight measuring metering device such as load cells.

[0021] A biomass gasifier reactor and receiver control system and chemistry control system may include a feed-rate control system that manages variations in solar energy. The sources of concentrated solar energy to the solar thermal receiver includes one or more solar energy concentrating fields consisting of 1) an array of heliostats, 2) solar concentrating dishes, and 3) any combination of the two. The design of the multiple reactor tubes and solar thermal receiver are adapted per a solar flux profile to take advantage of variations in the concentrations of solar flux in the solar flux profile. These adaption can include, for example, adapting 1) an amount of the at least two or more reactor tubes present in the cavity of the solar thermal receiver, 2) a size diameter of each of the reactor tubes in which the reactor tubes may have different diameters, 3) a shape pattern of the multiple reactor tubes relative to each other, 4) a shape of each individual reactor tube may vary with respect to other tubes 5) a size, shape, and orientation of the apertures or windows relative to the concentrated solar energy coming from the array of heliostats or solar concentrating dishes, 6) and other similar adaptations.

[0022] The solar driven chemical reactor 200 can be contained within the solar thermal receiver. The inner walls of the solar thermal receiver and the chemical reactor 200 may be made from materials selected to transfer energy by primarily heat radiation, along with convection, and conduction to the reacting biomass particles to drive the endothermic gasification reaction of the particles of biomass flowing through the chemical reactor.

[0023] Some embodiments may include a computerized control system configured to balance the gasification reaction of biomass particles with the available concentrated solar energy and additional variable parameters of a fixed range of particle size, temperature of the chemical reactor 200, and residence time of the particles in a reaction zone in the chemical reactor. This may be done so that an overall biomass particle conversion remains above a threshold set point with substantial tar destruction to less than below 50 mg/m^3 and gasification of greater than 90 percent of the particles into reaction products that include hydrogen and carbon monoxide gas.

[0024] A feedforward portion and a feedback portion of the computer control system may be used to adapt to both long and short term disturbances in available solar energy. For example, the feedforward portion may anticipate, for example, either or both immediate and short-term changes, or cyclic changes in solar energy due to at least a time of day, day of the calendar it is, and periodic weather reports, such as daily or hourly weather reports. The anticipation may be generated with a predictive model that adapts to the anticipated cyclic changes. The feedback portion measures actual process parameters including the temperature of the chemical reactor at an entrance and an exit. Additionally, the system may compensate for missing data, such as missing weather reports.

[0025] The computerized control system may send a feed demand signal to the feed system to control a feed rate of particles of biomass in the solar driven chemical reactor by changing a gas pressure and/or volumetric flow rate of the entrainment carrier gas in combination with a metering device controlling a weight, volume, or quantity of biomass particles from a lock hopper to the feed lines that feed the chemical reactor. The computerized control system may be one of a Programmable Logic Controller, computer, computer numerical controlled machine, similar control system, etc.

[0026] As discussed, the solar-driven bio-refinery can include a chemical reactor 200 that has multiple reactor tubes 202, 204, 206, 208 in which the biomass particles flow in. Two or more reactor tubes in the chemical reactor tubes might be used. The example illustrated includes five reactor tubes. The fixed range of particle size of biomass used can be controlled to an average smallest dimension size between 50 microns (um) and 2000 um, with a general range of between 200 micrometer and 1000 micrometer. Additionally, the temperature at an exit from the tubes 202, 204, 206, 208 of the chemical reactor may be maintained at a steady state temperature exceeding 1000 degrees C, above transitory minimum temperature of 800 degrees C and below peak temperatures of 1600 degrees C. Further, the residence time of the particles in the reaction zone in the chemical reactor 200 can be between a range of 0.01 and 5 seconds.

[0027] Some embodiments include two or more sensors including temperature sensors at the entrance and exit of the chemical reactor and one or more light meters to provide information to the feedback portion of the computer control. This information can include an amount of solar energy available indicated by system.

[0028] A separate feed line can be used to feed biomass particles for each of the reactor tubes 202, 204, 206, 208 in the chemical reactor 200, which can allow independent temperature control and balancing of the amount of particles of biomass flowing in each of the reactor tubes in the multiple tube solar driven chemical reactor.

[0029] The receiver cavity, the multiple reactor tubes, and the one or more apertures or windows are shaped and sized to facilitate greater than 60% average aperture/window incident power to be converted into chemical/sensible energy at peak incident power; and thus, greater than 60% the amount of energy entering the receiver as solar energy ends up as chemical or sensible enthalpy leaving the reactor tubes, and also a conversion of carbon in the particles of biomass to CO (and in some cases, CH_4 or other hydrocarbons) above 85% yield of the biomass occurs from the gasification reaction. In some embodiment, the apertures or windows are shaped and sized to facilitate greater than 75% average aperture/window incident power to be converted into chemical/sensible energy at peak incident power.

[0030] In some embodiments, the receiver cavity, the multiple reactor tubes, and the one or more apertures or windows are shaped and sized to map an amount of solar flux distribution to the reactor tube size and geometric position to allow essentially a same rate of biomass gasification for a set biomass particle size range everywhere in a gasification zone in the tubes of the chemical reactor, and thus avoiding locally extremely high temperatures (>1500 C) or extremely low temperatures (<600 C).

[0031] Figure 3 illustrates a diagram of an example solar tower 300 with receivers 302 and heliostat field 304. In some embodiments solar tower 300 may be used to from a solar-driven bio-refinery with an entrainment flow biomass feed system. The feed system can be feedstock flexible via, for example, particle size control of the biomass.

[0032] A chemical reactor 306 receives concentrated solar thermal energy from an array of heliostats 304. The chemical reactor 306 can be, for example, a multiple reactor tube, downdraft, solar driven, chemical reactor, which receives concentrated solar thermal energy from the array of heliostats. A solar tower 300 may form a portion of a solar-driven bio-refinery that may also include a biomass feed system that has balancing of the feed lines to each of the reactor tubes in a multiple tube chemical reactor. For example, biomass may be feed to the solar reactor 306 in an operation including three parts: biomass transport and preparation for feeding to the solar tower reactor 306, biomass transport to the top of the, e.g., 500+ foot tower 300, and distribution into the specific downdraft tubes of the reactor 306. The distribution may be performed via multiple stages.

[0033] The tower 300 supporting the elevated solar thermal receiver 302 and solar driven chemical reactor 306 is tall enough, such as at least 150 meters, in height to give an optimized angle of elevation for the non-uniform heliostat field. In some embodiments, a height of at least 100 meters may provide an optimized angle of elevation for the non-uniform heliostat field.

[0034] Thus, the tower 300 that supports and elevates the solar thermal receiver 306 and solar driven chemical reactor 302 can use a tower that is at least 100 meters in height to give an optimized angle of elevation. This may allow for a large fraction of the heliostat area, such as over 50%, to be visible from the point of view of the secondary concentrator. This, in turn, may increase the concentration of solar energy at the apertures, improves the overall efficiency, and results in a higher plant capital utilization factor. The solar energy may enter the receiver through one or more apertures. In some embodiments, the tower may be 50 meters or higher in height.

[0035] In some embodiments, each heliostat has a mirror. The array of mirrors in the heliostat field are configured to obtain both 1) dense packing in at least the first third of the part of the field near the receiver and 2) optimal small shading. The highest proportion of energy off of each of the mirrors in the dense packed portion of heliostats intercepts the one or more apertures or windows of the receiver. Optimal small shading and minimal blocking occurs for the mirrors in the heliostat field due to 1) the angle of elevation of the heliostat field to the solar thermal receiver on the tower, in combination with 2) the staggered heights and 3) the spacing of the rows of the non-uniform heliostat field. In an embodiment, the heliostats may have a long focal point.

[0036] In some embodiments, a solar-driven chemical reactor can include a high concentration of the sun's energy directed from the one or more solar energy concentrating fields to the receiver to give a normal distribution equal to or greater than 3000 – 5000 kW per meters squared peak solar energy in the flux at the apertures of the receiver cavity. In another embodiment, the flux at the apertures of the receiver cavity may have an average solar energy of 750-3500 as the useable/achievable range, and the preferred range of 1000-2500 kW/m^2 range depending on the time of day, in order to have a capacity of at least 2000 kW and generally around 80,000 kW. In one example, the multiple tube construction of the cavity increases the surface area for radiative transfer to the reactants in the chemical reaction over a common reaction tube. The receiver may have high fluxes of 3000 – 5000 kW per meters squared peak solar energy right at the aperture but these fluxes fall off as the light approaches the reactor tubes and tube wall to 100-300 kW/m^2.

[0037] Some embodiments can include one or more actuators. The receiver has the one or more apertures that are not covered with a window. The one or more apertures can be articulated moveable apertures that are capable of varying location on the solar thermal receiver, e.g., on top of the tower 300. These movements may depend on the time of day or season of the year and be based on the actuators moving the apertures.

[0038] A computing device, such as a PLC controller, a computer, etc., may run a model of solar energy flux maps of the apertures that captures how the solar power delivered to the aperture changes over time under similar natural solar conditions in order to send control signals to and guide the actuators in moving the apertures.

[0039] The cavity of the solar thermal receiver may contain additional radiant heat masses, which have high temperature storage material that absorb the concentrated solar energy. The structures may be used as radiant heat masses to keep the reactor tubes hot during long periods of off sun, during cyclic up and down times in the plant, as well as keep radiant temperature in the reactor more stable/less transient during normal operation. One or more of these radiant heat masses can be positioned in the cavity in areas of extremely high concentrated solar energy compared to other areas within the cavity to absorb some of the concentrated solar energy in that area to allow the reactor tubes to all use the same material. These radiant heat masses may also be heated by non-solar sources such as gas burners or electrical devices.

[0040] One or more apertures or 2) windows can be part of a receiver outer shell that at least partially encloses the multiple reactor tubes 202, 204, 206, 208. The size and shape of the one or more apertures may be determined by the heliostat field, which can focus into the apertures or windows a total amount of light in sun concentrations that is needed for the short residence times balanced against an efficiency of a solar energy being concentrated from the non-uniform heliostat field.

[0041] Additionally, a material making up the receiver inner wall may absorb concentrated solar energy, or may be a material that highly reflects, such as refractory alumina or SiC plate, to cause the radiant heat and then generally radiatively conveys that heat like an oven to the biomass particles in the reactor tubes. An insulation of brick, ceramic, or fiber with a thickness of, for example, 24 cm covers an outer wall/shell of the receiver. The inner wall may operate at high (>1200 ℃) wall temperatures and the insulation thickness is designed so as to limit losses through conductive heat loss to less than 5% of the energy incident at peak solar input on the receiver apertures or windows. A radiation shield, such as a door, that is moveable across the aperture at night or other periods of extended shutdown is used to minimize an amount of radiation heat loss, which enables a rapid heat up to gasification temperatures when normal operations resume such as in the morning. In some embodiments, the insulation thickness and door are designed so as to limit losses through conductive heat loss to less than 2% of the energy incident at peak solar input on the receiver.

[0042] An insulation layer can be included around the cavity of the indirect radiation driven geometry, absorbing cavity, and solar thermal receiver. The receiver might have one or more apertures and no windows. Additionally, the cavity of the receiver may also have a high concentration of solar energy at the one or more apertures. The multiple reactor tubes are located in the center of the cavity. The thickness of the insulation layer can be set to control conductive heat losses. In some examples, radiative losses may be controlled by the cavity temperature and an average concentration of solar energy at the one or more apertures.

[0043] The solar thermal receiver may further include a thick layer of insulation that limits heat losses by conduction from a cavity of the receiver. A moveable insulative door on the receiver aperture limits heat losses by radiation from the cavity during periods of inclement weather or during nighttime, so that the temperature in the cavity is decreased by less than 400 ℃ in a 12-hour period when no concentrated solar energy is directed at the cavity aperture. The door and insulation reduce the amount of time required to heat the receiver following a down period and lessen the thermal shock and stresses imparted to the receiver and reactor materials. In some embodiments, the receiver may include a pump to move molten salts through tubes in the receiver walls for use in electrical power generation.

[0044] In some embodiments, an aperture design, orientation, and cavity working fluid (buoyancy) may be set to control convective losses The cavity may at least partially enclosing the multiple reactor tubes and may acts like an oven, spreading heat flux around through radiation. In this way, the system can give a much more even flux profile on the reactor tubes (azimuthally and axially) than the incident solar radiation has. Accordingly, an averaging effect on the heat flux radiated from the absorbing cavity walls and multiple tubes occurs within the cavity.

[0045] Some embodiments include an axis of the reactor tubes with a heliostat solar field that focuses the moving Sun to shift the concentrated solar energy from a West to an East weighting across the aperture impinging on the axis of the reactor tubes themselves through the course of each day. The oven effect of the cavity, along with the particles, may tend to average energy amongst themselves at their design volumetric loadings and combine to give a fairly uniform temperature profile and subsequent fairly uniform reaction profile of the biomass particles.

[0046] One or more incident radiation shaping surfaces such as baffles may be used on the reactor tubes. These baffles may be positioned at select locations within the cavity of receiver and combined with an intertube radiation exchange between the multiple reactor tube geometric arrangement relative to each other is used to shape a distribution of incident radiation via reflection or absorption within the receiver cavity.

[0047] A secondary concentrator on the solar thermal receiver may be used to boost concentration of the concentrated solar energy, in which a surface geometry of the secondary concentrator and a field layout of the one or more solar energy concentrating fields is designed to avoid reflective and absorptive losses in the cavity of the solar thermal receiver.

[0048] Figure 4 illustrates a graph of cumulative particle size distribution. The graph illustrates the weight percentage below *Y percentage* for a given screen size in microns. Four example materials are illustrated, knife-chopped rice straw at 48 kilowatt-hours per ton, knife-chopped rice straw with an unknown energy value per ton, miscanthus stems at 35 kilowatt-hours per ton, and rice straw at 190 kilowatt-hours per ton. The smaller the size of the particle of the various types of biomass, the less difference in the way the feed system and reactor view particles from different types of biomass. The average size of ground particles may be correlated to filter particle size used in standard filter ranges.

[0049] In one embodiment a material and an indirect gasification design of the multiple reactor tubes allows for feedstock flexibility in the type of biomass making up the particles of biomass. This can obviate a need for an exothermic/endothermic reaction balancing because heat radiation from the concentrated solar energy primarily drives the endothermic gasification reaction and the heat radiation-based heat transfer balancing makes the endothermic reaction gasification quite forgiving in terms of internal reaction balance. Thus, at least two or more different types of biomass materials might be used in the same reactor tube geometry. This obviates any need for a complete reengineering when a new type of biomass feedstock is used. The two or more different types of biomass materials that can be fed from the feed system, individually or in combinational mixtures, are selected from the group consisting of rice straw, rice hulls, corn stover, switch grass, non-food wheat straw, miscanthus, orchard wastes, sorghum, forestry thinning, forestry wastes, source separated green wastes and other similar biomass sources. These sources might be used interchangeable as long as a few parameters are controlled such as the particle size of the biomass.

[0050] Figure 5 illustrates a diagram of a solar thermal receiver 500 with gasifier tubes 502. Solar thermal receiver 500 can form a portion of a solar-driven bio-refinery. The solar-driven bio-refinery can include a solar-driven chemical reactor, a solar thermal receiver such as receiver 500, or both as shown in figure 5. In some embodiments, solar thermal receiver 500 can be a multiple reaction tube downdraft solar thermal receiver as well as solar-driven chemical reactor. Additionally, the feed system may feed biomass particles into the multiple reaction tubes 502, in which the particles of biomass may be gasified in the presence of steam at a temperature exceeding 950 degrees C from an exit of a gasification reaction zone of the reactor tubes. The tubes arrangement, diameters, and shape are adapted to the flux profile.

[0051] The size and shape of one or more apertures in the receiver and the current temperature of the cavity of the receiver enclosing the chemical reactor can be set to make radiation losses directly calculable. An insulation layer around the cavity may be set thick enough to control conduction losses to, e.g., less than 2% of the peak solar input, wherein once the reactor is heated up to operational temperatures, due to the conduction losses to less than 2% and the radiation losses being directly calculable the receiver cavity temperature is a controlled parameter. The receiver cavity temperature may then be primarily controlled by modulating the flow rate of biomass particles through the reactor tubes balanced against the predicted feed-forward available amount of solar energy and the dynamically determined feedback amount of available solar energy.

[0052] Some embodiments may include one or more apertures that may be open to the atmosphere or covered in a transparent window, to pass the concentrated solar energy into the solar thermal receiver to impinge on the multiple reactor tubes and cavity walls of the receiver and transfer energy by solar radiation absorption and heat radiation, convection, and conduction to the reactants in the chemical reaction, such as the particles of biomass.

[0053] This transfer of energy may drive the endothermic chemical reaction flowing in the reactor tubes. The design of the multiple reactor tubes and solar thermal receiver can be adapted per a solar flux profile to take advantage of variations in the concentrations of solar flux in the profile. For example, adapting can include 1) an amount of the at least two or more reactor tubes present in the cavity of the solar thermal receiver, 2) a size diameter of each of the reactor tubes in which a first reactor tube has a different diameter than a second reactor tube, 3) a geometric arrangement of a shape pattern of the multiple reactor tubes relative to each other, 4) a shape of each individual reactor tube may vary with respect to other tubes per the flux profile to take advantage of variations in solar flux in the profile, i.e., areas with larger amounts of direct and incident solar flux as well as adapt for areas with a lower amount of solar flux; and 5) a size, shape, and orientation of the apertures or windows relative to the concentrated solar energy coming from the array of heliostats or solar concentrating dishes.

[0054] Materials selected for the inner cavity wall and the reactor tubes and an amount of concentrated solar energy from one or more solar energy concentrating fields combine to cause high heat transfer rates from the cavity walls and reactor tubes. The endothermic chemical reaction can be biomass gasification. The high heat transfer rates allow particles of biomass flowing in the reactor tubes to achieve a high enough temperature necessary for substantial tar destruction and gasification of greater than 90 percent of the biomass particles into reaction products including hydrogen and carbon monoxide gas in a very short residence time between a range of 0.01 and 5 seconds.

[0055] The length and diameter dimensions of a gasification reaction zone of each of the reactor tubes, along with an arrangement and an amount of the tubes are matched to an amount of sun concentration from the heliostat field to give the fast residence time of 0.01 second to 5 seconds, with the preferred residence time of 0.5-3 seconds, at the biomass gasification temperatures. The multiple tubes may have different diameters such as a larger diameter than another tube in the multiple tubes. The larger diameter tubes can be located in a higher solar energy concentration and higher temperature zone in the cavity of the receiver. Additionally, the geometrical configuration of the multiple reactor tubes in the receiver relative to each other is in a linear pattern, semi circular pattern, arc pattern, cylindrical pattern, rectangular pattern, or other appropriate configuration. An inner diameter of the tubes may be sized to allow a substantially uniform gasification of the biomass particles from the edges to the center of the tube. The wall thickness of the tubes may be in a range of 1/8”-2" to withstand at least a 75 psig pressure on the inside tube walls at 1400 ℃.

[0056] For example, the tubes can be oriented vertically in the solar receiver cavity, and may be 2-30" (3-16” preferred) in inner diameter with a 1/8”-2" wall thickness to withstand the 75 psig pressure on the inside tube walls. The arrangement, shape, and pattern of a group of tubes may be an arc, cylinder, rectangle, or a semi circle in shape. In general, more thermal energy is available at the top of the group shape without a presence of a secondary concentrator. The more tubes equals more surface area than one big tube and more uniform heating because diameter is smaller than one big tube. Additionally, the receiver shape may not be cylindrical when used with a multiple receiver tower site. The more even temperature profile is obtained in the more central tubes as opposed to the outer tube, giving a longer residence time at high temperature. The first reactor tube is located above the second reactor tube. The higher oven temperature zone may have the bigger tubes in diameter, as well as the bigger diameter tubes may be located in other areas of the receiver.

[0057] Some embodiments include a receiver that has two or more zones in which the reactor tubes and the receiver cavity in each zone are made out of different material. This can be done to adapt to an amount of solar flux in that zone, a peak temperature of that zone, and corrosion/steam conditions in that zone. Additionally, the shape of each tube can be a cylindrical shaped pipe or of another geometry such as a rectangular shaped pipe, for example. The shape of the reactor tubes being substantially rectangular will yields a higher surface area for equivalent volume than cylindrical shaped tubes.

[0058] In an embodiment, the amount of reactor tubes present in the cavity of the solar thermal receiver will be in a preferred range of 120-150 reactor tubes, with a range encompassing as few as 30 reactor tubes and as many as multiple 100s. Each reactor tube will have the same size diameter the rest of the reactor tubes. The geometric arrangement of the multiple reactor tubes relative to each other will be arc pattern with probably more than one row. The shape of each individual reactor tube will all be cylindrical. The expected size, shape, and orientation of the aperture in the receiver relative to the concentrated solar energy coming from the array of heliostats or solar concentrating dishes will be approximately 7 meters by 7 meters square. The length and diameter dimensions of the gasification reaction zone in the reactor tubes is the inner diameter of the tubes will be 6 inches and stretch the full length of the tube such as 9 meters long.

[0059] A tower 300 that supports and elevates the solar thermal receiver and solar driven chemical reactor may be used in some embodiments. The tower 300 is at least tall enough, such as equal to or greater than 100 meters, in height to give an optimized angle of elevation for the one or more solar energy concentrating fields to supply the concentrated solar energy to the solar thermal receiver and solar driven chemical reactor while minimizing an amount of heliostats or solar concentrating dishes and acreage of land occupied by these heliostats or solar concentrating dishes needed to deliver an amount of concentrated solar energy to the apertures or windows of 750-3500 kW m^{-2} as the useable/achievable range. The concentrated solar energy to the apertures or windows exceeding 750 kW m^{-2} achieves the high heat transfer rates of the inner wall of the cavity and reactor tubes causes the particles biomass to achieve the high enough temperature necessary for substantial tar mitigation and gasification of greater than 90 percent of the biomass particles into reactant products.

[0060] Figure 6a and 6b illustrate block diagrams of embodiments of the entrained-flow biomass feed system 600. Different types of feed systems may be used in conjunction with a biomass into reactor, for example, drop tube, total solid feed into the reactor, slurry fed into the reactor, a moveable bed in the reactor, or combinations of these schemes.

[0061] One or more feeding vessels in the biomass feed system supply two or more reactor tubes in the solar-driven chemical reactor. Each of the feeding vessels has one or more outlets configured to supply a consistent volumetric amount of biomass particles within 10 percent of the demand signal amount when distributing biomass particles to the two or more reactor tubes. For example, the injection rate to each injection point into carrier gas lines is within +/-10% of the desired demand signal amount.

[0062] One example solar-driven bio-refinery may include the entrained-flow biomass feed system 600 that includes or otherwise cooperates with a grinding system. The grinding process 603 and feed process may be 1) processes separated in time and completed independently of the other process or 2) a continuous process of the where the grinding process 603 occurs and immediately feeds biomass into the feed system and then into the chemical reactor.

[0063] An objective of the feeding system is to feed as many reactor tubes as possible with the fewest number of feeding vessels such as lock-hopper systems.

[0064] The grinding system 603 has a mechanical cutting device used to grind the biomass into primary particles, which are to be fed into the solar driven chemical reactor. The grinding system supplies primary particles that have an average smallest dimension size between 200 microns (um) and 2000 um, with a general range of between 500 um and 1000 um to a lock hopper system 604 with a standard belt conveyer. The biomass particles are then fed across a pressure boundary into a pressurized entrainment gas for feeding into in the solar driven chemical reactor. The feeding vessel may use an Auger/Screw feeder or an airlock-type rotational solids feeding/rate metering device.

[0065] As illustrated in Figure 6a, the entrainment-flow biomass feed system 600 can include a pressurized lock hopper 604 that feeds the biomass to a rotating screw conveyor 602 and a metering device and then into an entrainment gas pipe at the lock hopper exit 606. A flow splitter distributes the particles of biomass into multiple entrainment gas lines to feed at least two or more of the multiple reactor tubes making up the solar driven chemical reactor. The entrainment gas for the entrainment flow biomass feed system may be a pressurized dry steam generated from waste heat recovered from either 1) the methanol/Methanol-To-Gasoline (MTG) units in the hydrocarbon fuel synthesis process 2) the products from the gasification reaction in the solar driven chemical reactor 3) other gases such as natural gas, carbon dioxide or 4) combinations thereof.

[0066] As illustrated in Figure 6a and 6b, the feed rate of the biomass particles can be controlled by a metering device and controlling a rotational rate of a screw 602 or other rotational device at a base of the lock hopper 604, which responds to a feed demand signal received from the computerized control system.

[0067] Some embodiments may also allow for controlling the rotational rate of the screw or auger 602 that can move set amounts of biomass along the axis of rotation of the auger 602. The auger 602 may be located at the base of the lock hopper 604 and can be controlled by a computerized control system such as a Programmable Logic Controller, or via different data communication protocols using a Personal Computer, Macintosh Computing device, CNC, various combinations of these systems, etc, to respond to feed demand of the system. In an embodiment, the computerized control system controls the feed rate of particles of biomass in the solar driven chemical reactor based on an amount of solar energy available indicated by sensors including temperature sensors and/or light meters.

[0068] Figure 7 illustrates a diagram of a solar-driven chemical refinery 800. In such a system, solar power from a concentrating field 802 may be provided through a window or aperture 804 to a solar heated reactor chamber 806. An array of heliostats 802 can be used to focus light onto the aperture 804 of receiver around the reactor 806. A quencher 808 may be used to prevent back reaction. As illustrated, biomass particles flow into the system at 810 and syngas flows out. Additionally, a heat exchange may occur to recoup waste heat from the exiting biomass particle remnants and the syngas.

[0069] In some embodiments, steam may be injected along with the particles of biomass during the gasification reaction. This may shift some of the product carbon monoxide to additional hydrogen and carbon dioxide gas, making the hydrogen to carbon monoxide ratio appropriate for methanol synthesis. In such an embodiment, the inside walls of the reactor tubes may be are made of corrosion resistant materials with a resistance to steam of between a good to excellent rating.

[0070] In some embodiments, a composition analyzer at the exit of the reactor system may be used to sense changes in hydrogen, carbon monoxide, carbon dioxide, water, methane and tar composition of the syngas. The composition analyzer provides a dynamic signal to the feedback portion of the control system. Upon readings of reaction product components that are too high above a threshold, the control system can divert the reactant products to a reactor recycling line or to a flare to avoid damage to compressors, catalytic systems, and other components in the methanol synthesis plant.

[0071] In some embodiments, a carrier gas supply line can supply the entrainment gas as a pressurized dry steam. Natural gas may be fed along with the biomass particles during a co-gasification of 1) biomass in the presence of steam and 2) steam reforming of natural gas.

[0072] In reactor 806 biomass particles can be reduced to syngas, which in turn can be synthesized into liquid fuel in liquid fuel synthesizer 808. Examples of liquid hydrocarbon fuel include, but are not limited to one or more of jet fuel, DME, gasoline, diesel, methanol, and mixed alcohol, synthetic natural gas production, and heating oil generation.

[0073] In some embodiments, an amount of surface area, thermal mass, and heat capacity may be built into two or more reactor tubes and receiver cavity. One or more temperature sensors at the entrance and exit of the reactor tubes may be used to monitor the solar-driven bio-refinery. An operational temperature range of below 1600 degrees C and above 800 degrees C in the chemical reactor might be achieved during daily weather conditions, which are subject to rapid changes in solar availability.

[0074] In some embodiments, a feed demand signal from the control system can be used to control the feed rate of particles of biomass in the solar driven chemical reactor. This control can be performed using a feedforward/feedback model-predictive scheme. Such a scheme might be used in cooperation with designing in enough surface area, thermal mass, and heat capacity in the multiple tubes and receiver cavity to ensure that temperature of the reactor cavity remains in the operational temperature range of below 1600 degrees C and above 800 degrees C. These temperatures might be maintained during rapidly changing daily weather conditions. In some examples, the feed forward model can predict a maximum, minimum, and average available solar energy over each time period in a given day as well as each day throughout the year.

[0075] The feed-forward portion utilizes a histogram of events affecting an amount of available solar energy categorized into at least three general time durations. Events may further be categorized as short events of 1 to 5 hours, often caused by passing clouds; medium events of 5-14 hours, often caused by diurnal effects (for our mid latitudes), long term events of 14 hours or more, generally caused by more major weather events. The time of day, the day of the calendar and the daily weather report may also be considered with respect to feed-forward implementations.

[0076] The feedback portion may receives dynamic feedback from temperature sensors and combine this data to maintain both the quality and output of resultant syngas at above a threshold set point of substantial tar destruction to maintain tar at or below 50 mg/m^3 and gasification of greater than 90 percent of the biomass particles into the reaction products. In one example, enough surface area and thermal mass of the cavity and reactor tubes is built into the multiple tubes and receiver cavity in relation to the feed rate of biomass particles, to act as a ballast, averaging out very short term small fluctuations (second to second) in the available solar energy. This thermal mass causes a very low ramp-up and ramp-down of temperature of the reactor due to these instantaneous changes in available solar energy; and thereby, allow the ramp-up and ramp-down of the feed rate of biomass particles to be gradual as well.

[0077] In some embodiments, the control system can use a complex feedforward/feedback model-predictive scheme to ensure that temperature of the reactor cavity remains in the required range. The feedforward components use meteorological measurements, geographical factors, and time of day/day of year to predict the rate of change of available solar energy and make process adjustments accordingly. Additionally, the feedback component of the control checks these predictions against real time data to make appropriate corrections balanced by not overcorrecting or under correcting for the instantaneous changes in solar energy conditions. This control approach gives robust system operation with a highly transient system input: sunlight.

[0078] In some embodiments, the carbonaceous biomass material particles being fed from the entrained flow biomass feed system undergo several distinct chemical processes of the gasification reaction prior to exiting the reactor tubes. These processes include pyrolysis of the carbonaceous biomass particles into 1) carbonaceous char and 2) volatile components vaporized into gas products. The process also include gasification of the carbonaceous char including the lignin fractions into both 1) gaseous products, including carbon monoxide, hydrogen, and tars, as well as 2) greater than 99 % pure carbonaceous ash. The process includes cracking of the tars including larger hydrocarbons and aromatic compounds collectively known as tars. This gasification can occur at greater than 1000 degrees C to the produce the substantial tar destruction to less than 50 mg/m^3 and gasification of greater than 90 percent of the biomass particles into reaction products including hydrogen and carbon monoxide gas. The steps of gasification and cracking of tars starts and finishes within the residence time of the biomass particles in the reaction zone in the chemical reactor between the range of 0.01 and 5 seconds.

[0079] As discussed above, in various embodiments, gasification of the carbonaceous char including lignin occurs. Lignin is a complex chemical compound derived from biomass, and an integral part of the secondary cell walls of plants. Lignin fills the spaces in the cell wall between cellulose, hemicellulose, and pectin components. Additionally, preheating of the biomass prior to being fed into the reactor tubes may raise the temperature above 200 degrees C beginning the pyrolysis process.

[0080] In some embodiments, the shape and width of the outlet of the feed line pipe carrying the biomass particles to its corresponding reactor tube may be used to control a dispersion pattern of biomass particles entering each reactor tube. Greater than 90 % conversion may occur because of both 1) the high operating temperatures and 2) that the biomass particles are well separated from one another in a flowing dense cloud of very fine biomass particles. An amount of oxygen, air, or steam co-currently flowing in the gasification of the biomass particles can be controlled to cause a selectivity of carbon reactant from the biomass to become CO rather than CO2 at better than a 10:1 selectivity to CO over CO2.

[0081] In various embodiments, the control system can use both feedforward (based on anticipated changes) and feedback (based on actual measured changes) elements to control the balancing of gasification reaction occurring to result in negligible tar formation in resultant syngas products and waste products. Control strategies discussed herein have been developed to manage a variation in solar energy due to changes in solar energy and a cyclic operating state.

[0082] In some embodiments, a material making up the reactor tubes can possess high emissivity such as 0.7 emissivity coefficient or better, high thermal conductivity such as 30 watts per meter-Kelvin or better, at least moderate heat capacity of 8 joules per mole–degree Kelvin or better. The material can also be resistant to the oxidizing air environment in the receiver cavity and the reducing environment of the biomass gasification reaction inside the tubes in order to support operating temperatures within the tubes in the tar-cracking regime above 1000ºC. This operating temperatures eliminates any need for tar cracking equipment downstream of the chemical reactor, and where in addition operation at the high operating temperature improves heat transfer, eliminates methane from the exit gases, decreases required residence time of the biomass particles to achieve gasification, which in turn decreases the physical size of the solar chemical reactor.

[0083] Figure 8 illustrates a flow diagram. In step 900, biomass grinding can occur. Equipment generally used for grinding biomass includes impact mills (e.g. hammer mills), attrition mills, and kinetic disintegration mills (e.g. flail mills). A hammer mill system can be used to grind the bales (loaded by conveyer) into primary particles, which are to be fed into the solar thermal gasifier. The re-ground particles have an average size between 500 µm and 1000 µm, and are loaded into the lock hopper system with a standard belt conveyer.

[0084] In step 902 biomass feeding occurs. In some embodiments, high pressure feeding may be used. High pressure feeding of solids of biomass with gasification at pressure may reduce capital cost due to the ability to use smaller compressors in some such systems. Additionally, operating cost may be reduced because energy for pressurizing carrier gas comes from the sun, as opposed to from electricity. The lock hopper system can feed the reactor processes at pressure. For example, the feeding system can entrain the biomass materials in steam at high pressure, successfully disengage the particulates in the cyclone system, and distribute flow appropriately to the reactor tubes.

[0085] In step 904 gasification occurs. For example, in some embodiments, concentrated solar thermal energy drives gasification of the particles of the biomass to generate at least hydrogen and carbon monoxide products from the gasification reaction.

[0086] In step 906 fuel synthesis occurs. An on-site fuel synthesis reactor can receive the hydrogen and carbon monoxide products from the gasification reaction and use the hydrogen and carbon monoxide products in a hydrocarbon fuel synthesis process to create a liquid hydrocarbon fuel. The fuel synthesis reactor may be geographically located on the same site as the chemical reactor and integrated into the process to utilize the hydrogen and carbon monoxide products from the gasification reaction.

[0087] Some embodiments of the solar-driven bio-refinery include one or more spray nozzles to supply water to the product gas exiting the chemical reactor to shift some of the product carbon monoxide to additional hydrogen and carbon dioxide gas in a water gas shift reaction. The reaction is designed to make the hydrogen to carbon monoxide ratio appropriate for methanol synthesis, such as a H2:CO ratio in the synthesis gas within the range 2.0 to 2.7.

[0088] An insulation layer around the receiver can include resistance heaters connected to the outer wall of the receiver to assist with maintaining temperature in the 800-1600 degree C range. Waste heat from a quenching unit quenching the gasification products heats high temperature storage material in hot beds in an exit of the receiver. The waste heat is used with a material or working fluid, e.g. molten salts, for use in electrical power generation to supply a source of power for including at least the resistance heaters. The control system can turn on and off the resistance heaters as additional heat sources for maintaining temperature as need be. The control system supplies a control signal to the feed system, the solar energy concentrating fields, the supplemental resistance heating system and potentially to a recirculation system. The lag times and response times of the: 1) heliostat field to alter alignment and an amount of concentrated solar energy supplied, 2) feed system to alter an amount of biomass flowing in the reactor tubes, 3) time for weather events to alter an amount of solar energy available, such as 30 seconds for a passing cloud, are factors taken into account by a control algorithm in the computerized control system in sending out the control signals to the feed system, the solar energy concentrating fields, and the supplemental resistance heating system.

[0089] Some embodiments relate to reactor control, receiver control, control of the flux profile, etc. Such systems and methods may include adapting tubes/reactor per the flux profile to take advantage of variations in solar flux in the profile, modifying parameters to control flux across aperture, and shaping incident radiation.

[0090] An example solar-driven chemical reactor system can include a solar thermal receiver aligned to absorb concentrated solar energy from one or more solar energy concentrating fields. These fields can include an array of heliostats, solar concentrating dishes, or any combination of the two. Additionally, a solar driven chemical reactor may be used. The reactor can have multiple reactor tubes located inside the solar thermal receiver, where in the multiple reactor tubes an endothermic chemical reaction driven by radiant heat occurs. The multiple reactor tubes in this reactor design may increase available reactor surface area for radiative exchange to the reactants as well as creates an inter-tube radiation exchange. Additionally, the endothermic chemical reaction includes one of the following biomass gasification, steam methane reforming, methane cracking, steam ethane cracking to produce ethylene, metals refining, carbon dioxide capture and other similar endothermic carbon-based chemical reactions can be conducted in this reactor using solar thermal energy.

[0091] In some embodiments, a first solar energy concentrating field can be a non-uniform heliostat field with a staggered height of the heliostats. Where a farther away a row of heliostat is from the receiver, then the height of the heliostats in that row is increased and also a spacing between heliostat rows is increased as the row of heliostat moves away in distance from the solar thermal receiver. The non-uniform heliostat field is used to generate the concentrated solar energy at greater than or equal to 500 sun concentrations with a secondary concentrator or 1,000 sun concentrations with no secondary concentrator focused at the apertures or windows of the receiver for the solar driven chemical reactor.

[0092] The solar-driven chemical reactor system can include a non-uniform heliostat field has >25,000 m^2 of reflecting surface, >50,000 m^2 of reflecting surface, or >100,000 m^2 of reflecting surface, that cooperates with the solar thermal receiver to have an ability to control an amount of solar energy flux across the apertures or windows. A heliostat field with other total reflective surfaces areas may also be used.

[0093] The reflecting surface cooperates with the solar thermal receiver to have an ability to control an amount of solar energy flux across the apertures or windows that is applied to reactor tubes and cavity walls to allow enough energy from a radiant energy to raise the heat inside the tubes. This increase in the heat may initiate and sustain a sufficiently high temperature so that gasification occurs of greater than 90 percent of the biomass particles into reactant products. The reactant products can include hydrogen and carbon monoxide gas in the very short residence time between the range of 0.01 and 5 seconds and a preferred range of 0.01 to 2 seconds. The size and a shape of the one or more apertures or windows can determined by the heliostat field trying to focus into the apertures or windows a total amount of light in sun concentrations that is needed for the short residence times balanced against an efficiency of a solar energy being concentrated from the non-uniform heliostat field.

[0094] The methods and apparatuses of the invention in some cases may be implemented using computer software. If written in a programming language conforming to a recognized standard, sequences of instructions designed to implement the methods can be compiled for execution on a variety of hardware platforms and for interface to a variety of operating systems. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein. Furthermore, it is common in the art to speak of software, in one form or another (e.g., program, procedure, application, driver, etc.), as taking an action or causing a result. Such expressions are merely a shorthand way of saying that execution of the software by a computer causes the processor of the computer to perform an action or produce a result.

[0095] A machine-readable medium is understood to include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium includes read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; flash memory devices, etc.

[0096] While some specific embodiments of the invention have been shown the invention is not to be limited to these embodiments. The invention is to be understood as not limited by the specific embodiments described herein, but only by scope of the appended claims.

CLAIMS

What is claimed is:

We claim:

1. A solar-driven chemical reactor system, comprising:

a solar thermal receiver aligned to absorb concentrated solar energy from one or more solar energy concentrating fields including either 1) an array of heliostats, 2) a solar concentrating dish, or 3) any combination of the two;

a solar driven chemical reactor that has multiple reactor tubes located inside the solar thermal receiver, where an endothermic chemical reaction driven principally by radiant heat occurs in the multiple reactor tubes, where the multiple reactor tubes in this reactor design increase available reactor surface area for radiative exchange to the reactants as well as creates an inter-tube radiation exchange, wherein the endothermic chemical reaction includes one or more of the following: biomass gasification, steam methane reforming, methane cracking, steam ethane or naphtha cracking to produce ethylene and related olefins, metals refining, carbon dioxide splitting, or water splitting to be conducted in this chemical reactor using solar thermal energy coming from the concentrated solar energy; and

one or more apertures in the receiver 1) open to an atmosphere of the Earth or 2) with a transparent window covering the aperture, to pass the concentrated solar energy into the solar thermal receiver to impinge on the multiple reactor tubes and cavity walls of the receiver and transfer energy by absorption, re-radiation, convection, and conduction to the reactants in the chemical reaction to drive the endothermic chemical reaction flowing in the reactor tubes, wherein a design of the multiple reactor tubes and solar thermal receiver are adapted per a solar flux profile to take advantage of variations in concentrations of solar flux in the solar flux profile including adapting two or more of 1) an amount of the at least two or more reactor tubes present in the cavity of the solar thermal receiver, 2) a size diameter of each of the reactor tubes in which a first reactor tube may have a different diameter than a second reactor tube, 3) a geometric arrangement of the multiple reactor tubes relative to each other, 4) a shape of each individual reactor tube may vary with respect to other tubes per the flux profile to take advantage of variations in solar flux in the profile and 5) a size, shape, and orientation of the apertures relative to the concentrated solar energy coming from the solar energy concentrating field.

2. The solar-driven chemical reactor system of claim 1, wherein the endothermic chemical reaction is at least biomass gasification, and

where materials selected for the inner cavity wall and the reactor tubes combined with an amount of concentrated solar energy from one or more solar energy concentrating fields cause heat transfer from the cavity walls and reactor tubes to transfer heat in a sufficient amount to the particles of biomass flowing in the reactor tubes to achieve the temperature necessary for substantial tar destruction and gasification of greater than 90 percent of the biomass particles into reaction products, including hydrogen and carbon monoxide gas, in a very short residence time between a range of 0.01 and 5 seconds.

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3. The solar-driven chemical reactor system of claim 2, further comprising:

a length and diameter dimensions of a gasification reaction zone of each of the reactor tubes, along with an arrangement and an amount of the tubes are matched to an amount of solar energy from the heliostat field to give the fast residence time of 0.01 second to 5 seconds, with the preferred residence time of 2-3 seconds at the biomass gasification temperatures of greater than 950 degree C, where the first of the multiple tubes that has a different diameter than the second of the multiple tubes, has a larger diameter, and is located in a higher solar flux concentration and/or higher temperature zone in the cavity of the receiver than the second tube,

where the geometrical configuration of the multiple reactor tubes in the receiver relative to each other is in a linear pattern, semi circular pattern, arc pattern, cylindrical pattern, rectangular pattern, or some other arbitrary arrangement,

wherein an inner diameter of the reactor tubes is sized to allow a substantially uniform gasification of the biomass particles from the edges to the center of the tube, and have a wall thickness in a range of 1/8”-2", that is set to withstand at least a 75 psig pressure when the inside tube walls are at 1400 ℃, and

an on-site chemical synthesis reactor that is geographically located on the same site as the chemical reactor and has an input to receive the gasification products including hydrogen and carbon monoxide for a hydrocarbon synthesis process performed in the on-site chemical synthesis reactor to create hydrocarbon fuels and/or chemicals.

4. The solar-driven chemical reactor system of claim 2, wherein a shape of each reactor tube is a cylindrical shaped pipe, at least 30 reactor tubes are present in the cavity of the solar thermal receiver, the geometric arrangement of the at least 30 reactor tubes relative to each other is an arc pattern, and a shape of the aperture is approximately a square, and

wherein at least some the products resulting from the chemical reaction in the solar driven chemical reactor are supplied to an input of a downstream chemical synthesis processes, in which methanol is generated and then supplied to a Methanol-to-Gasoline process.

5. The solar-driven chemical reactor system of claim 2, further comprising:

two or more zones in the receiver in which the reactor tubes in each zone are made out of different materials to adapt to 1) an amount of heat flux in that zone, 2) peak temperature of that zone, and 3) corrosion conditions in that zone,

a tower that supports and elevates the solar thermal receiver and solar driven chemical reactor, wherein the tower is at least tall enough, equal to or greater than 100 meters, in height to give an optimized angle of elevation for the one or more solar energy concentrating fields to supply the concentrated solar energy to the solar thermal receiver and solar driven chemical reactor while minimizing an amount of heliostats or solar concentrating dishes and acreage of land occupied by these heliostats or solar concentrating dishes needed to deliver an amount of concentrated solar energy to the apertures with a flux in the range of 750-3500 kW m^{-2}, and

wherein the concentration of solar energy into the apertures achieves the heat transfer rates at the inner wall of the cavity and reactor tubes to allow the particles of biomass to achieve the temperatures necessary for substantial tar mitigation to less than 50 mg/m^3 and to gasification of greater than 90 percent of the biomass particles into reactant products.

6. The solar-driven chemical reactor system of claim 2, wherein a first solar energy concentrating field is an arrangement of heliostats in rows of differing spacing such that as the distance of each row of heliostats from the receiver is increased, then the height of the heliostats in that row is increased and also the spacing between heliostat rows is increased, and where the non-uniform heliostat field is used to generate an average concentration of solar energy at the aperture of the receiver greater than or equal to 500 times the direct

normal insolation concurrently incident upon the solar energy concentrating field.

7. The solar-driven chemical reactor system of claim 6, wherein the heliostat field has >25,000 m^2 of reflecting surface that cooperates with the solar thermal receiver to control an amount of solar energy into the apertures and onto the reactor tubes and cavity walls thereby maintaining the temperature required for gasification of greater than 90 percent of the biomass particles into the reactant products that include the hydrogen and carbon monoxide gas in a residence time between the range of 0.01 and 5 seconds, and where the size and a shape of each of the one or more apertures of the receiver is determined by the balance between the power in the portion of the focus of the heliostat field accepted into the aperture and the total amount of energy that is needed to achieve the residence times.

8. The solar-driven chemical reactor system of claim 6, wherein the heliostat field has >100,000 m^2 of reflecting surface that cooperates with the solar thermal receiver to have an ability to control an amount of solar energy flux across the apertures that is applied to reactor tubes and cavity walls to allow enough energy from a radiant energy to raise the heat inside the tubes to initiate and sustain a sufficiently high temperature so that the gasification occurs of greater than 90 percent of the biomass particles into the reactant products that include the hydrogen and carbon monoxide gas in a residence time between the range of 0.01 and 2 seconds, and

wherein the solar energy concentrating field generates an average concentration of solar energy at the aperture of the receiver greater than or equal to 1000 times the direct normal insolation concurrently incident upon the solar energy concentrating field.

9. The solar-driven chemical reactor system of claim 1, further comprising:

baffles positioned at select locations within the cavity of receiver and combined with an intertube radiation exchange between the multiple reactor tube geometric arrangement relative to each other is used to shape a distribution of incident radiation via reflection or absorption within the receiver cavity,

wherein the concentrated solar energy field is a heliostat field and the concentrated solar energy from the heliostat field is in an amount of concentration of suns sufficient to produce equal to or greater than 750 kW per meters squared of solar energy at the apertures, which gives the receiver cavity to have a capacity of at least 2000 kW, wherein the multiple tube construction of the cavity increases the surface area for radiative transfer to the reactants in the chemical reaction over a common reaction tube, and

a shape of the reactor tubes is substantially rectangular, which also yields a higher surface area for equivalent volume than cylindrical shaped tubes.

10. The solar-driven chemical reactor system of claim 6, further comprising:

a tower supporting an elevated solar thermal receiver and solar driven chemical reactor, wherein the tower is tall enough, at least 100 meters, in height to give an optimized angle of elevation for the non-uniform heliostat field; and

each heliostat has a mirror, where the array of mirrors in the heliostat field are configured to obtain both 1) dense packing in at least the first third of the part of the field near the receiver, where the highest proportion of energy off of each of the mirrors in the dense packed portion of heliostats intercepts the one or more apertures or windows of the receiver and 2) optimal small shading and minimal blocking occurs for the mirrors in the heliostat field due to 1) the angle of elevation of the heliostat field to the solar thermal receiver on the tower, in combination with 2) the staggered heights and 3) the spacing of the rows of the non-uniform heliostat field.

11. The solar-driven chemical reactor system of claim 2, further comprising:

a high concentration of solar energy directed from the one or more solar energy concentrating fields to the receiver to give a normal distribution equal to or greater than 3000 – 5000 kW per meters squared peak solar energy in the flux at the apertures of the receiver cavity, with an average solar energy in the 1000-2500 kW per meters squared range depending on the time of day, in order to have a capacity of at least 2000 kW and generally around 80,000 kW.

12. The solar-driven chemical reactor system of claim 2, wherein the receiver cavity, the multiple reactor tubes, and the one or more apertures are shaped and sized to facilitate greater than 60% average aperture incident power to be converted into chemical/sensible energy at peak incident power; and thus, greater than 60% the amount of energy entering the receiver as solar energy ends up as chemical or sensible enthalpy leaving the reactor tubes, and also a conversion of carbon in the particles of biomass to CO above 85% yield/ton of the biomass occurs from the gasification reaction in the tubes, and

wherein the receiver has one or more windows covering the apertures and no apertures open to the atmosphere.

13. The solar-driven chemical reactor system of claim 2, wherein the receiver cavity, the multiple reactor tubes, and the one or more apertures or windows are shaped and sized to map an amount of solar flux distribution to the reactor tube size and geometric position

to allow essentially a same rate of biomass gasification for a set biomass particle size range everywhere in a gasification zone in the tubes of the chemical reactor, and thus avoiding locally extremely high temperatures >1500 degrees C or extremely low temperatures <600 degrees C.

14. The solar-driven chemical reactor system of claim 1, further comprising:

one or more actuators, wherein the receiver has the one or more apertures and no windows, and wherein the one or more apertures are articulated moveable apertures that are capable of varying location on the solar thermal receiver based on the actuators moving the apertures, and

a computing device running a model of solar energy flux maps of the apertures that captures how the solar power delivered to the aperture changes over time under similar natural solar conditions in order to send control signals to and guide the actuators in moving the apertures.

15. The solar-driven chemical reactor system of claim 1, further comprising:

one or more structures with high temperature storage material that absorb the concentrated solar energy contained within the cavity of the solar thermal receiver, and

wherein the cavity of the solar thermal receiver contains additional radiant heat masses, which have high temperature storage material that absorb the concentrated solar energy, where the radiant heat masses are used to keep the reactor tubes hot during long periods of off sun, during cyclic up and down times in the plant, as well as keep radiant temperature in the reactor less transient during normal operation, and wherein one or more of these radiant heat masses are positioned in the cavity in areas of extremely high concentrated solar energy compared to other areas within the cavity to absorb some of the concentrated solar energy in that area to allow the reactor tubes to all use the same material.

16. The solar-driven chemical reactor system of claim 2, wherein the one or more apertures are part of a receiver outer shell that at least partially encloses the multiple reactor tubes, wherein a material making up the receiver inner wall absorbs, or the material highly reflects the concentrated solar energy to cause the radiant heat and then generally radiatively conveys that heat like an oven to the biomass particles in the reactor tubes, and one of a brick, a ceramic, or a fiber insulation covers an outer wall of the receiver, wherein the inner wall operates at high >1200 degrees C wall temperatures and the insulation thickness is designed so as to limit losses through conductive heat loss to less than 5% of the energy incident at peak solar input on the receiver apertures and a radiation shield that is moveable across the aperture at night or other periods of extended shutdown to minimize an amount of radiation heat loss, which enables a rapid heat up to gasification temperatures when normal operations resume such as in the morning.

17. The solar-driven chemical reactor system of claim 2, further comprising:

an insulation layer around the cavity of the indirect radiation driven geometry, absorbing cavity, solar thermal receiver, wherein the receiver is configured with only one or more apertures and no windows, and where the multiple reactor tubes are located in the center of the cavity;

a thickness of the insulation layer is set to control conductive heat losses, and where the cavity temperature and an average concentration of solar energy at the one or more apertures control radiative losses;

an aperture design, orientation, and cavity working fluid (buoyancy) are also configured to control convective losses, wherein the inner cavity wall at least partially encloses the multiple reactor tubes to act like an oven, spreading heat flux around via reflection or absorption and re-radiation and giving a much more even flux profile on the reactor tubes, both azimuthally and axially, than the incident solar radiation by itself has, wherein an averaging effect on the heat flux radiated from the absorbing cavity walls and multiple tubes occurs within the cavity; and

wherein the solar energy concentrating field is a heliostat field that focuses an average concentrated solar energy from the moving Sun of a West weighting to an East weighting across the aperture and subsequent impingement on the reactor tubes themselves through the course of each day, and yet the reactor tubes provide a uniform radial reaction profile of the biomass particles through the course of each day due to 1) the oven effect of the cavity along with 2) the particle nature of biomass, which tend to average energy amongst themselves at their design volumetric loadings, combining to give the fairly uniform temperature profile and subsequent fairly uniform radial reaction profile of the biomass particles.

18. The solar-driven chemical reactor system of claim 1, further comprising:

one or more incident radiation shaping surfaces including baffles at select locations within the cavity of receiver, along with the intertube radiation exchange between the multiple reactor tube geometric arrangement relative to each other is used to shape a distribution of incident radiation via reflection or absorption within the receiver cavity.

19. The solar-driven chemical reactor system of claim 1, further comprising:

a secondary concentrator on the solar thermal receiver to boost concentration of the concentrated solar energy, in which a surface geometry of the secondary concentrator and a field layout of the one or more solar energy concentrating fields is designed to avoid reflective and radiative losses from the area surrounding the aperture and the cavity of the solar thermal receiver; and

a tower that supports and elevates the solar thermal receiver and solar driven chemical reactor, wherein the tower is at least 100 meters in height to give an optimized angle of elevation, which allows for a large number of heliostats, including over 50% of the heliostat surface area making up the solar energy concentrating fields, to be visible from the point of view of the secondary concentrator, which increases the concentration of solar energy at the apertures, improves the overall efficiency, and results in a higher plant capital utilization factor, wherein the receiver has the one or more apertures and no windows.

20. A solar-driven chemical reactor system, comprising:

a solar thermal receiver aligned to absorb concentrated solar energy from one or more solar energy concentrating fields including either 1) an array of heliostats, 2) a solar concentrating dish, or 3) any combination of the two;

a solar driven chemical reactor that has multiple reactor tubes located inside the solar thermal receiver, where an endothermic chemical reaction driven by radiant heat occurs in the multiple reactor tubes using solar thermal energy coming from the concentrated solar energy; and

an aperture open to an atmosphere of the Earth to pass the concentrated solar energy into the solar thermal receiver to impinge on the multiple reactor tubes and cavity walls of the receiver and transfer energy to the reactants of the chemical reaction to drive the endothermic chemical reaction flowing in the reactor tubes, wherein a design of the multiple reactor tubes and solar thermal receiver are adapted per a solar flux profile to take advantage of variations in concentrations of solar flux in the solar flux profile including adapting 1) an amount of reactor tubes present in the cavity, 2) a size of the reactor tubes, 3) a geometric arrangement of the multiple reactor tubes relative to each other, and 4) a size, shape, and orientation of the aperture relative to the concentrated solar energy coming from the array of heliostats.

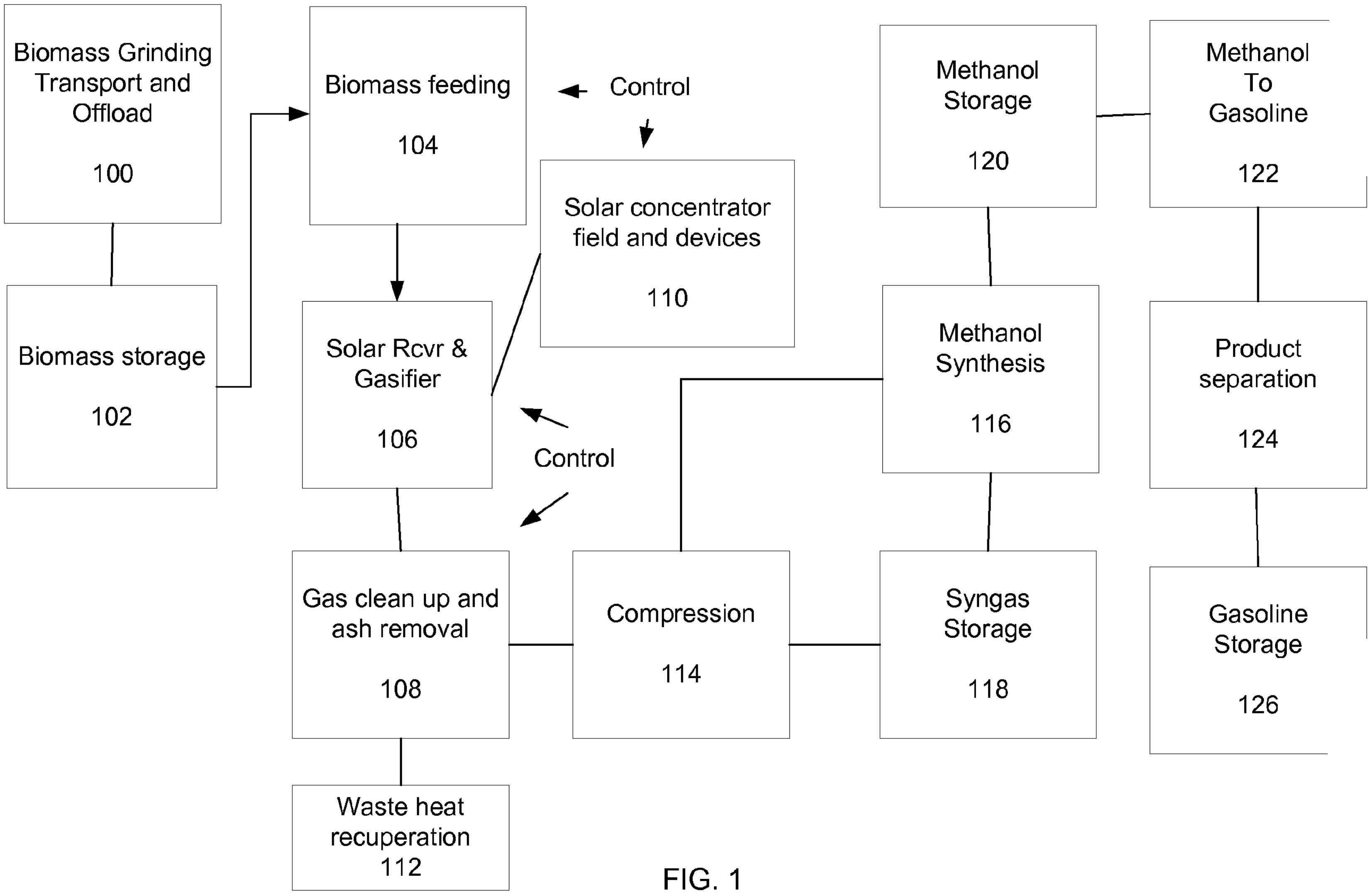
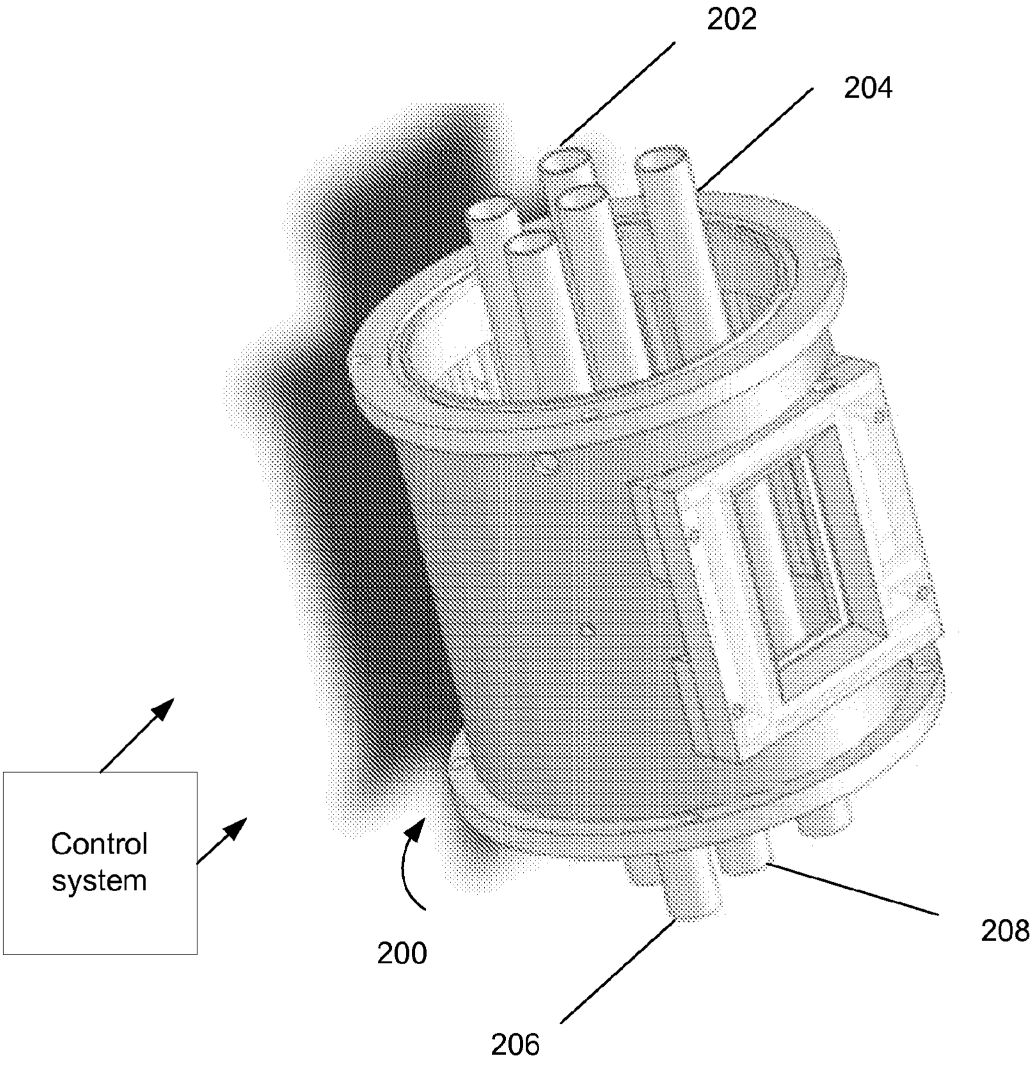

Biomass Grinding Transport and Offload
100
Biomass storage
102
Biomass feeding
104
Control
Solar concentrator field and devices
110
Solar Rcvr & Gasifier
106
Control
Gas clean up and ash removal
108
Waste heat recuperation
112
Compression
114
Methanol Storage
120
Methanol Synthesis
116
Syngas Storage
118
Methanol To Gasoline
122
Product separation
124
Gasoline Storage
126

FIG. 1



Multiple tube reactor

FIG. 2

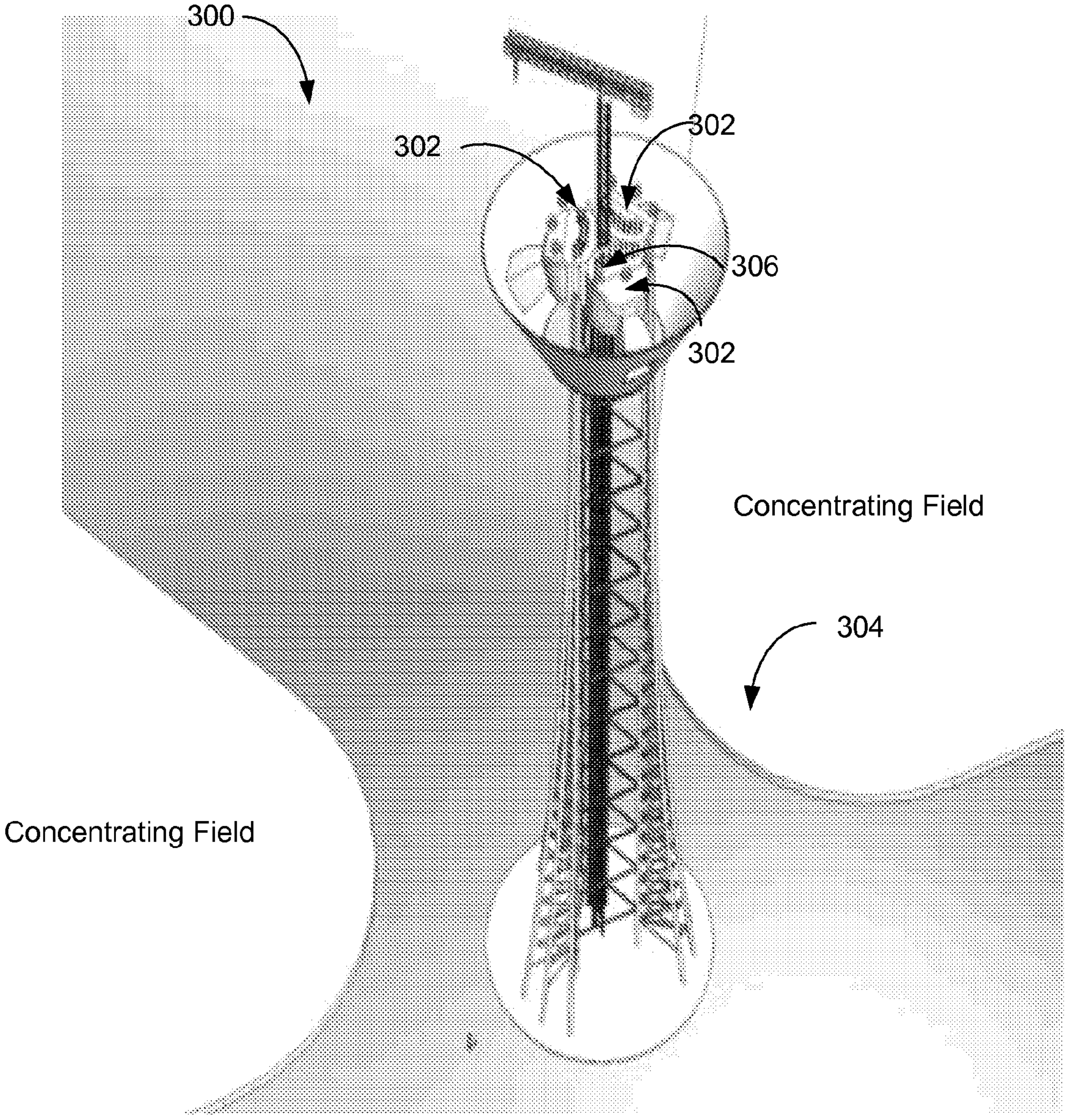

300
302
302
306
302
Concentrating Field
304
Concentrating Field

FIG. 3

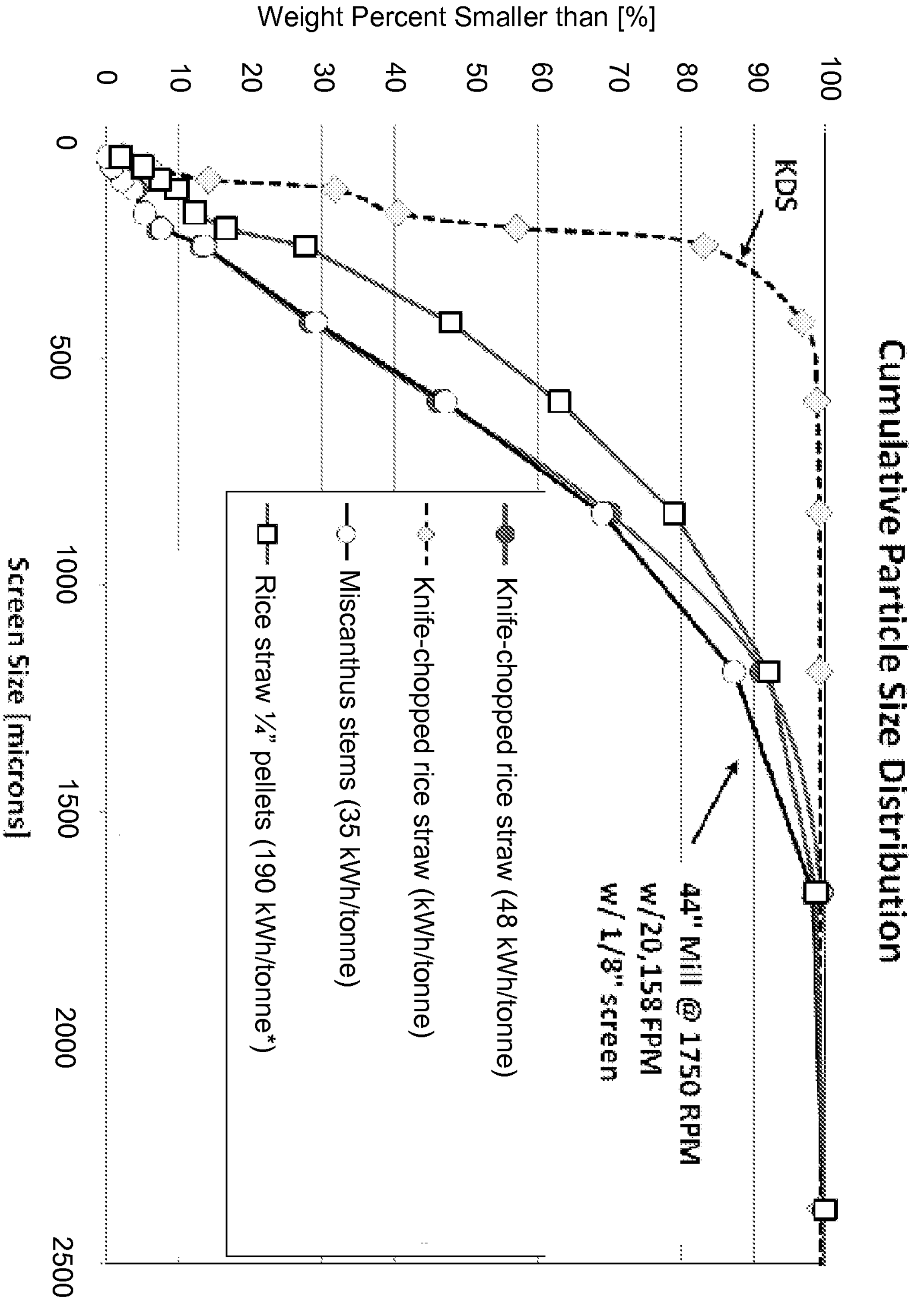

Cumulative Particle Size Distribution
Weight Percent Smaller than [%]
0
10
20
30
40
50
60
70
80
90
100
0
500
1000
1500
2000
2500
Screen Size [microns]
KDS
44" Mill @ 1750 RPM
w/20,158 FPM
w/ 1/8" screen
Knife-chopped rice straw (48 kWh/tonne)
Knife-chopped rice straw (kWh/tonne)
Miscanthus stems (35 kWh/tonne)
Rice straw ¼" pellets (190 kWh/tonne*)

FIG. 4

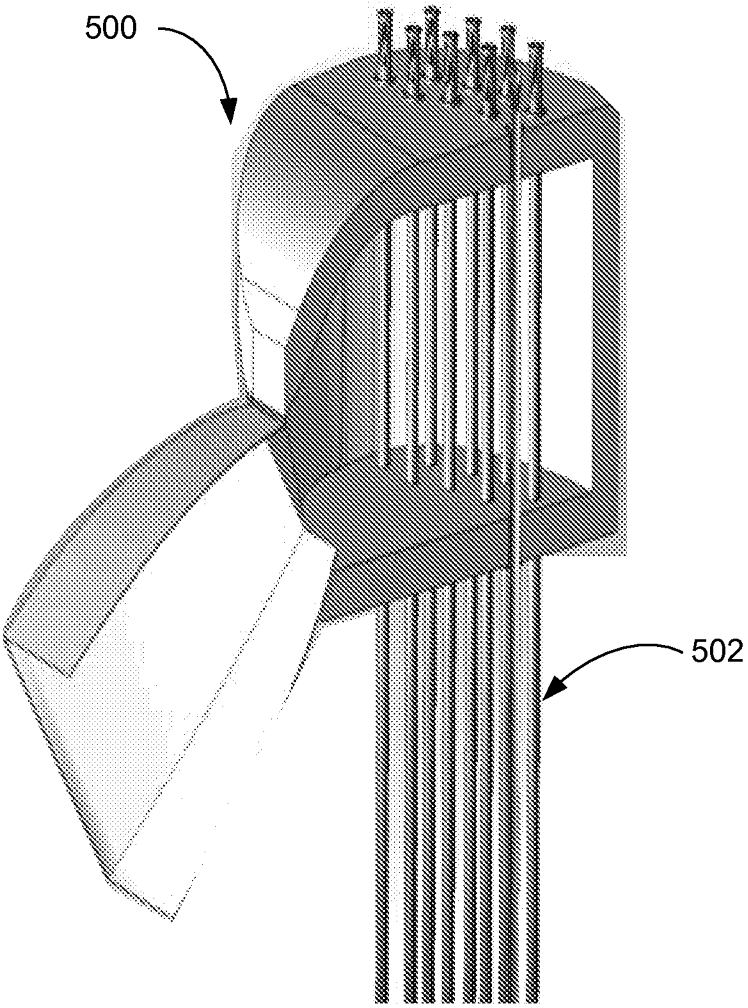


FIG. 5

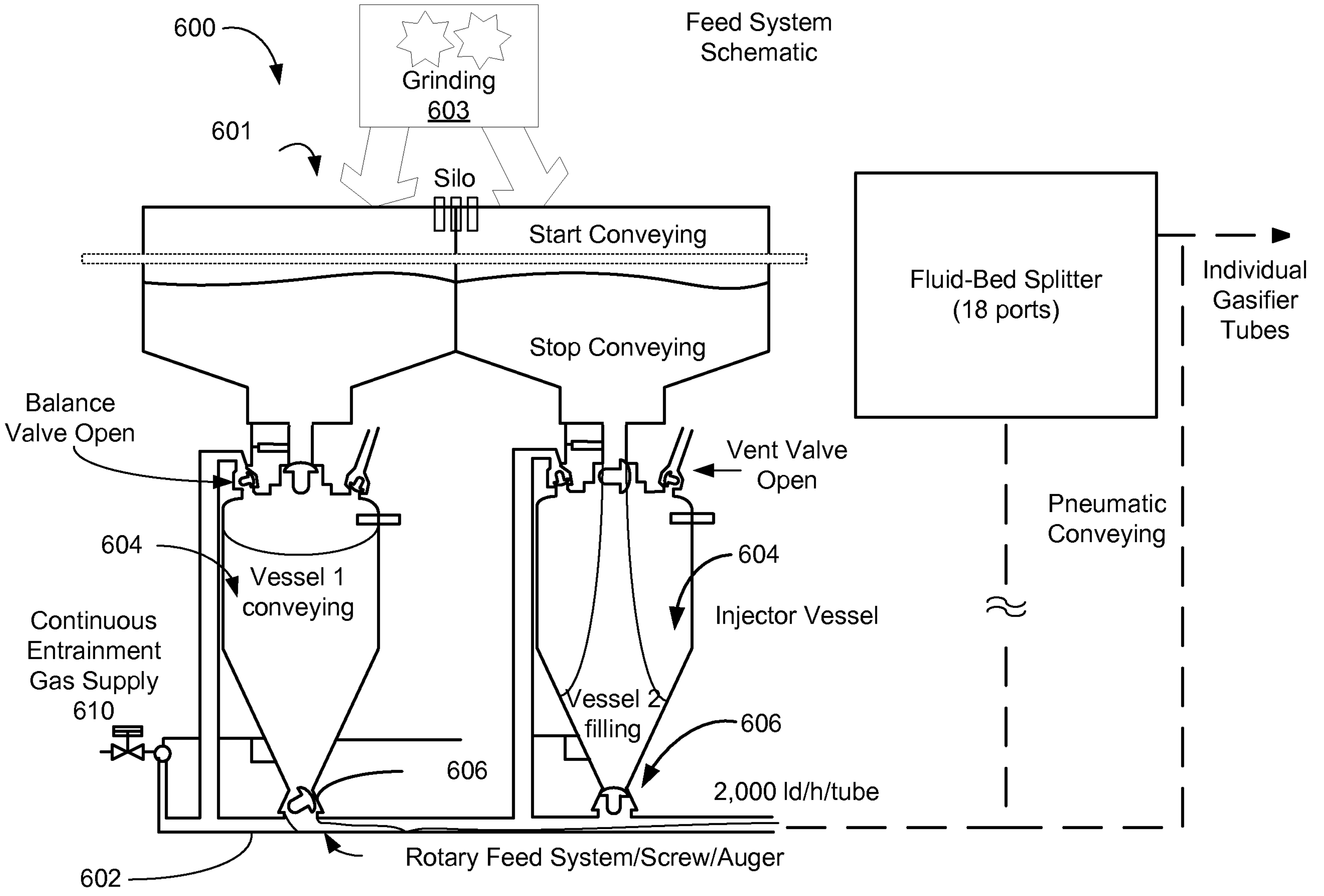

600
Grinding
603
Feed System
Schematic
601
Silo
Start Conveying
Stop Conveying
Fluid-Bed Splitter
(18 ports)
Individual
Gasifier
Tubes
Balance
Valve Open
Vent Valve
Open
604
Vessel 1
conveying
604
Injector Vessel
Pneumatic
Conveying
Continuous
Entrainment
Gas Supply
610
Vessel 2
filling
606
606
2,000 ld/h/tube
Rotary Feed System/Screw/Auger
602

FIG. 6a

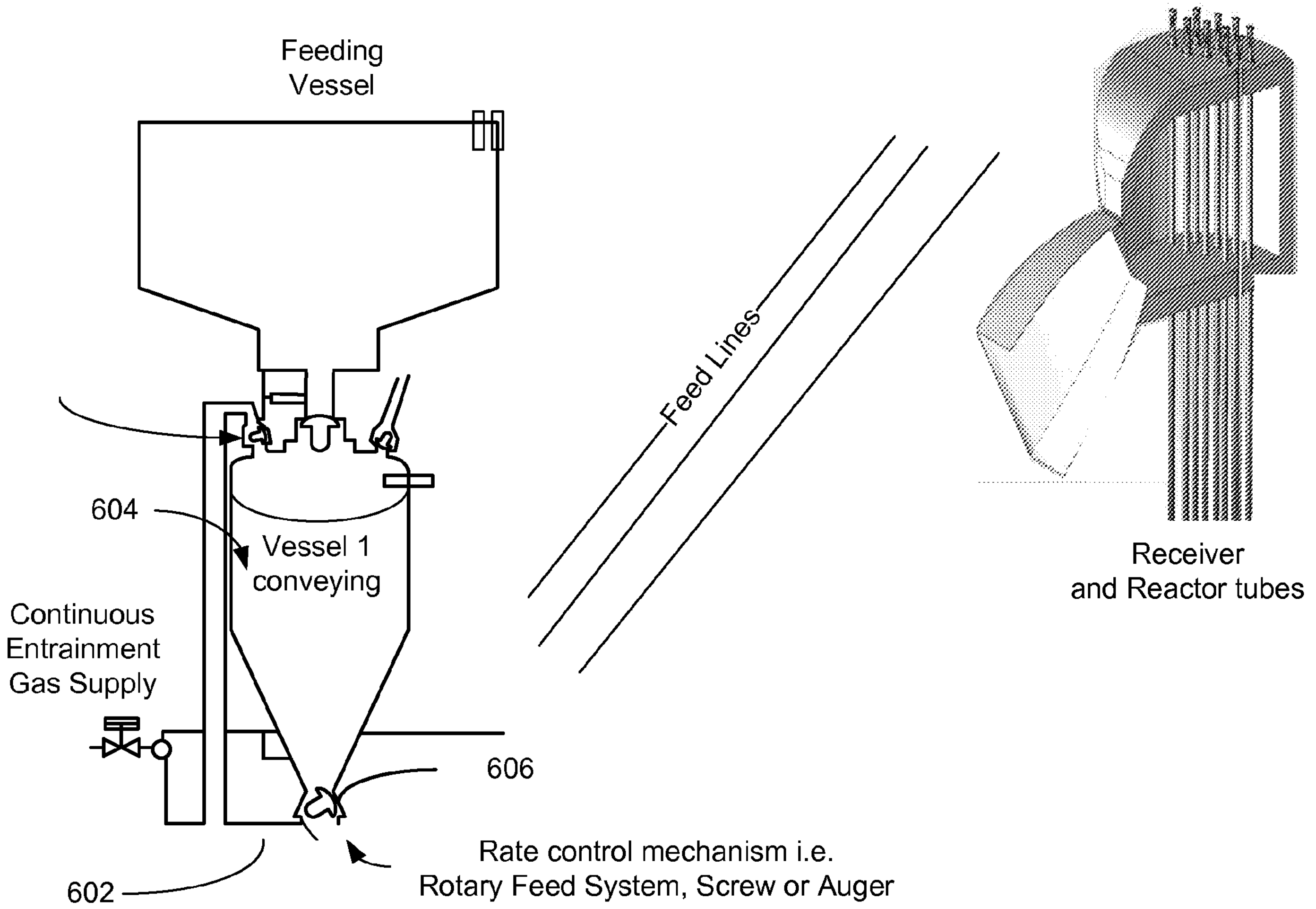

Feeding
Vessel
Feed Lines
Receiver
and Reactor tubes
604
Vessel 1
conveying
Continuous
Entrainment
Gas Supply
606
602
Rate control mechanism i.e.
Rotary Feed System, Screw or Auger

Figure 6b

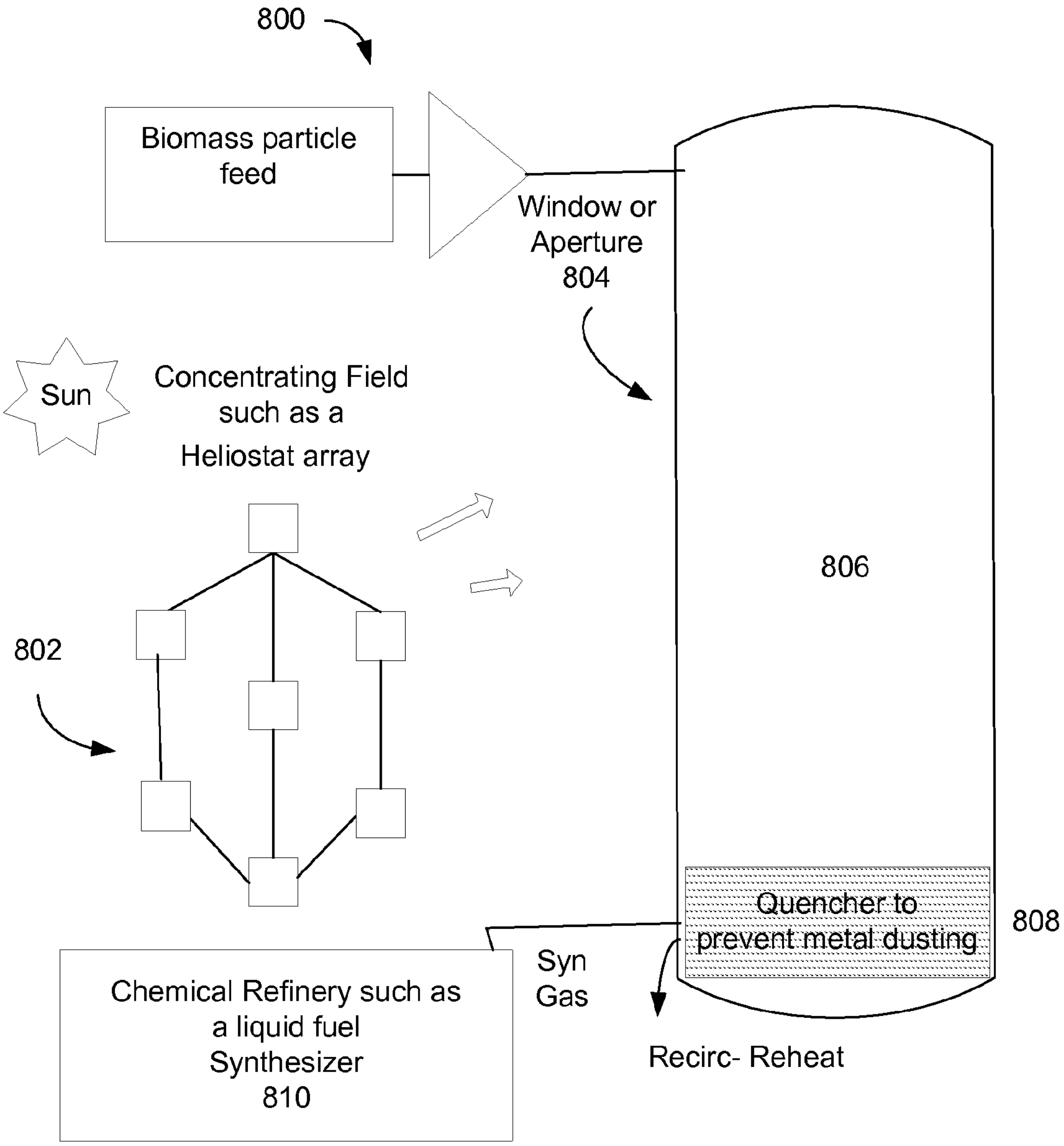

800
Biomass particle feed
Window or Aperture 804
Sun
Concentrating Field such as a Heliostat array
802
806
Quencher to prevent metal dusting
808
Syn Gas
Recirc- Reheat
Chemical Refinery such as a liquid fuel Synthesizer 810

FIG. 7

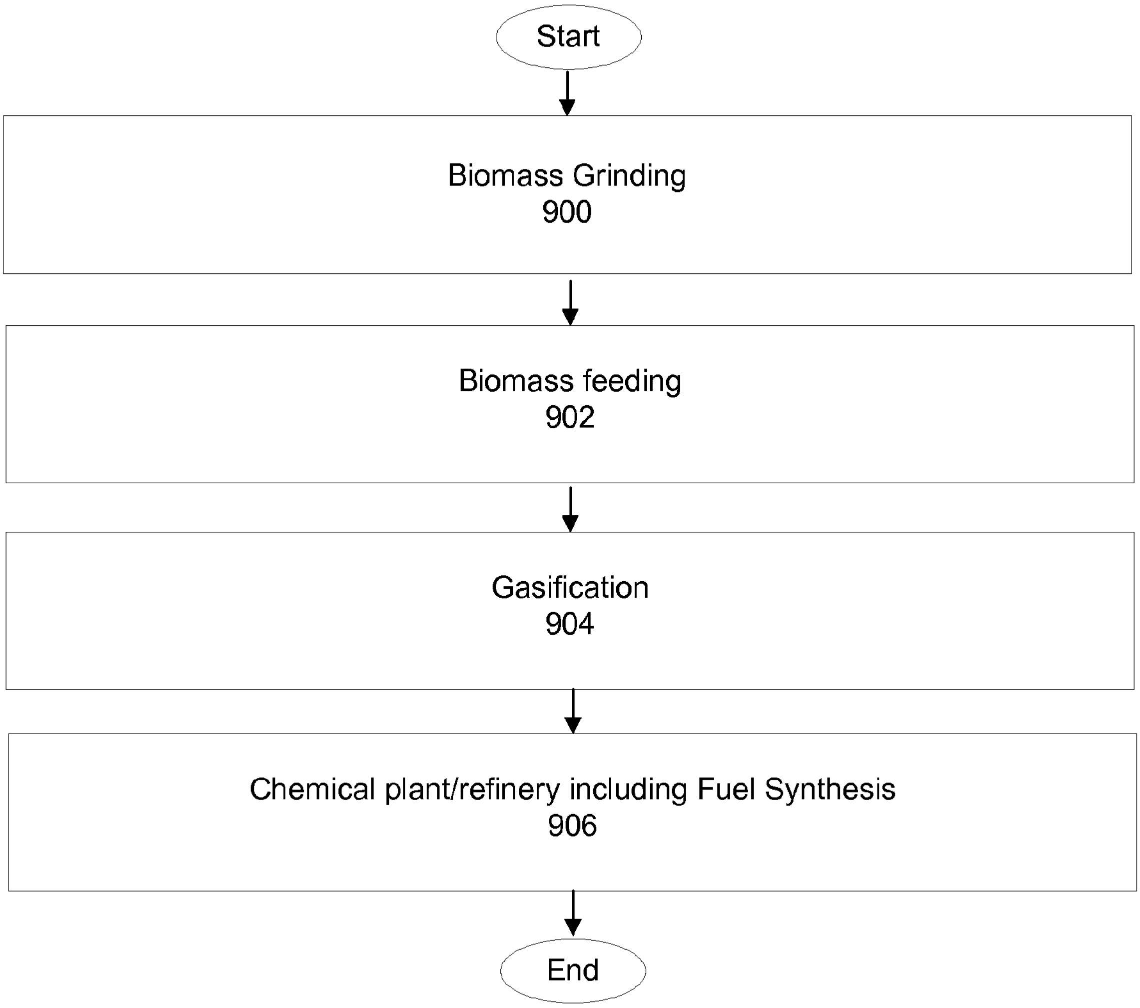

Start
Biomass Grinding
900
Biomass feeding
902
Gasification
904
Chemical plant/refinery including Fuel Synthesis
906
End

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 10/37944

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F25B 29/00 (2010.01)
USPC - 165/48.2; 34/93

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)
IPC (8) - F25B 29/00 (2010.01)
USPC - 165/48.2; 34/93

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC (8) - F25B 29/00 (2010.01)
USPC - 165/48.2; 34/93 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PUBWEST (PGPB,USPT,USOC,EPAB,JPAB) - Search terms - solar reactor watts tubes conduits pipes absorbers window aperture port target equilibrium absorbers pyrolysis gasification seconds biomass heliostat tower rotate turn flux hydrogen methanol array
Google - solar reactor (tubes OR conduits OR pipes) heliostat flux-profile; solar reactor tubes heli

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2008/0086946 A1 (WEIMER et al.) 17 April 2008 (17.04.2008), para [0010], [0027], [0030], [0034], [0042]-[0045], [0059]-[0062], [0068], [0085], [0088], [0099], [0132]; FIG. 2A	1-4, 6-8, 11-15, 17, 20 ------------------------- 5, 9, 10, 16, 18, 19
Y	US 4,164,123 A (SMITH) 14 August 1979 (14.08.1979), col 1, ln 61-65; col 2, ln 52 to col 3, ln 14	5, 10, 19
Y	US 2003/0213514 A1 (ORTABASI) 20 November 2003 (20.11.2003), para [0060]	9, 18
Y	US 2007/0129450 A1 (BARNICKI et al.) 07 June 2007 (07.06.2007), para [0052]	16

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 July 2010 (31.07.2010)	18 AUG 2010

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774