[0014] More recently, improvements to the apparatus and processes of the above patents for pyrolysis, gasification and vitrification of organic material, was disclosed in U.S. Pat. No. 6,987,792 to Do et al. This patent provides an improved material feeding system in order to enhance further the efficiency of the process as well as to increase the flexibility of the system, increase the ease of use of the material handling system, and allow the gasifier to receive a more diverse and varied material stream.

[0015] The apparatus and process of U.S. Pat. No. 6,987,792 ensures that high temperature is maintained in the bed zone through the use of plasma torches in conjunction with a catalyst bed. Additionally, the patent discloses several rings of tuyeres designed and located at different elevations of the bed to inject, for example, oxygen enriched air from the sides of the reactor to its center in order to maintain high temperatures and an efficient and complete gasification condition along the overall cross sections of the gasifier, while observing sub-stoichiometric conditions. The oxygen utilized in the U.S. Pat. No. 6,987,792 is supplied by a secondary source and is not produced integrally within and by the system.

[0016] Though the previously described systems and processes are useful, they represent early attempts for biomass gasification for purposes of production of renewable power and renewable liquid fuels rather than for renewable hydrogen production. As described above, current energy demands and fuel-based industries require access to green renewable hydrogen and renewable energy in an increasingly cost-effective and time efficient manner.

[0017] What is needed therefore, are efficient systems, processes and methods for the gasification of biomass to produce renewable green hydrogen such that the hydrogen is available for use, for transportation, and for other industrial applications. Preferably such systems, processes and methods should be easy to implement, cost-effective, efficient, reliable and compatible with the energy needs of the modern world.

SUMMARY

[0018] Provided herein are methods, devices and systems for one stage plasma-enhanced gasification of biogenic hydrocarbon waste material comprising the use of novel gasification units and systems. As contemplated herein the gasification units and systems of the disclosure comprise: unique geometric designed shaped reactors having an upper plenum section and a lower double bed section, wherein the lower double bed section comprises a first, wider portion connected by a frustoconical transition to a

second, narrower portion, and being suitable to receive a biochar carbon catalyst bed; wherein the upper plenum section has at least one or more gas exit ports; wherein a gas inlet system is disposed around said lower double bed section to provide oxidizing gas agent generated by an oxygen absorber system (such as a low cost oxygen (LCO) absorber system) into said lower double bed section through one or more intake ports in said lower section; and a plurality of inlets or tuyeres where plasma arc torches are mounted in said lower section to enhance the heat of oxidation generated from the said biochar carbon catalyst bed and said biogenic hydrocarbon waste material to create an operating temperature of 3000 to 5000 degrees Celsius. The integrated oxygen absorber system is designed to provide oxidizing agents in the form of atmospheric pressured oxygen enriched air, oxygen or steam to generate an autothermal exothermic oxidation of the biogenic hydrocarbon waste materials, introduced into the reactor.

[0018a] In one aspect, the present disclosure provides an apparatus for one stage plasma-enhanced gasification of biogenic hydrocarbon waste material comprising: (a) a geometrically designed shaped reactor having an upper plenum section and a lower double bed section, said lower double bed section comprising a first, wider portion connected by a frustoconical transition to a second, narrower portion, and being suitable to receive a proprietary biochar carbon catalyst bed; (b) said upper plenum section having at least one gas exit port; (c) a plurality of inlets for said biogenic hydrocarbon waste material from a plurality of directions located at the upper part of said lower double bed section for introducing said material into said upper portion of said lower double bed section; (d) a gas inlet system disposed around said lower section to provide oxidizing gas agent generated by an oxygen absorber system into said lower double bed section through one or more intake ports in said lower section; and (e) a plurality of inlets or tuyeres where plasma arc torches are mounted in said lower section to enhance the heat of oxidation generated from the biochar carbon catalyst bed and said biogenic hydrocarbon waste material to create an operating temperature of 3000 to 5000 degrees Celsius; wherein the integrated oxygen absorber system provides oxidizing agents in the form of atmospheric pressured oxygen enriched air, oxygen or steam to generate an autothermal exothermic oxidation of the biogenic hydrocarbon waste materials.

[0019] In previous examples of the gasifier system as described in U.S. Pat. No. 6,987,792, oxygen was provided by a secondary source, such as an over the fence supplier, at very high costs. In certain previous examples, oxygen was provided by a dedicated air-separation unit using cryogenic technology, a methodology which again was significantly costly resulting in high energy consumption. In general, because the step of supplying oxygen was separate from the overall process, the additional steps required in sourcing the oxygen, introducing it into the system, monitoring and managing the operational aspects of this process, resulted in inefficiencies as well as elevated costs. In an

effort to eliminate the aforementioned deficiencies, and in an effort to create streamlined, cost-effective and operationally superior systems and processes, the novel disclosure as described herein provides the unique feature which comprises the integration of an oxygen absorption mechanism into the gasifier.

[0020] The step of introducing oxygen from a separate source/location into the plasma gasification system is one that was described in previous patents and publications and routinely implemented in analogous devices. However, no prior art references, or systems disclosed or suggested the feature of actually integrating an oxygen absorption system directly into the gasifier. The concept of integrating an oxygen absorption system was neither envisioned nor reduced to practice until the creation of the disclosure as discussed herein. As such the features described herein are both novel and unobvious.

[0021] As described above, significant advantages are achieved by integrating an oxygen absorption system into the described plasma-based gasifier. First the integrated feature allows for oxygen to be produced at low pressure, requires minimal manual or

operational interaction, and accordingly results in a consistent output with ultimately lower costs. Furthermore, an oxygen absorption system according to the disclosure can be configured to generate steam which can be injected along with the oxygen enriched air to produce high purity renewable hydrogen.

[0022] The novel examples provided herein, comprise an oxygen blown process for producing renewable hydrogen enhanced by the external source of heat generated by plasma torches (allothermal process) producing an outlet syngas containing mainly hydrogen and carbon monoxide. Hydrogen and carbon monoxide are two molecular compounds which are most stable at high temperature; and accordingly, as a result of the high temperature gradient generated in the gasifier wherein the hottest temperature is found at the lowest oxidation zone and rising to the top plenum area, these molecular compounds are found in the plenum area where all residual hydrocarbon chains are further thermally cracked near the top of the gasifier before they exit. In certain examples of the disclosure, the high temperature gradient generates approximately five zones.

[0023] In accordance with the methods described herein, syngas is reliably produced from various organic hydrocarbon-feedstocks and is substantially free of tars or polycyclic aromatic hydrocarbons (which are normally generated by lower temperature autothermal gasification systems). The biomass derived syngas generated under atmospheric pressure in the gasifier is subsequently drawn out with a blower system, scrubbed of impurities and acid gases, and then cooled down to a lower temperature, in the process generating high pressure steam. The high-pressure steam heat is then used to maintain the temperature of the integrated oxygen absorber system which operates around 450 degrees Celsius to 550 degrees Celsius. The absorption process is an exothermic process, while the desorption process of oxygen is endothermic and therefore the process runs on equilibrium without requiring increasing significant heat transfer from the gasification reactor. The resulting scrubbed, cleaned and cooled syngas (which consists of approximately >65vol.% H2 and <35vol.% CO) is then compressed and fed into a water gas shift system together with pressurized water vapor to convert most of the CO and H2O into additional H2 and CO2. The off gas of the water gas shift reactor (if done with a one stage shift reaction which has a typical efficiency of 85%) contains mostly hydrogen gas and a much smaller volume of CO and CO2 and still contains sulfur containing compounds such as hydrogen sulfide, such as H2S, and carbonyl sulfide (COS) and other impurities, will be further compressed

required operating temperature of the gasifier, while optimizing the production of high purity hydrogen.

[0025] The apparatus described and referred to as a plasma-enhanced gasification system, contains one or more intake ports in the lower section where oxidizing agents such as air, enriched air with 90% to 95% oxygen, or steam is injected into the gas inlet system. The mode and quantity of oxidizing agent administration is determined according to the composition of the feedstocks, the volume of the feedstocks, the desired amount of hydrogen to be produced, and according to proprietary operational parameters to be designed and installed into the gasifier digital control system (DCS). The gas inlet system is integrated with a low cost oxygen absorbent system to provide only oxygen-enriched air or, in combination with steam, to assist in the oxidation and partial oxidation of the feedstock to enhance the amount of hydrogen produced in the synthetic gas output. A plurality of plasma arc torches is mounted in the lower section to heat the catalyst bed made up of a biochar material upon which the material being processed will be delivered on top creating a separate bed of feedstock materials. The catalyst bed helps distribute the heat evenly across the cross section of the apparatus preventing any channeling or bridging inside the fixed bed of feedstock materials above.

[0026] Another example of the present disclosure relates to methods for the conversion of material comprising waste, biomass or other carbonaceous material by plasma-enhanced thermocatalytic gasification into renewable hydrogen, wherein the methods comprise providing a carbonaceous biochar material to serve as a catalyst bed instead of using metallurgical or petroleum coke material in the oxidation zone section of a reactor. The biochar material comprises a dense carbon char material made from the pyrolysis of woody biomass (including but not limited to coconut shells) and further compressed into a char product which is denser and which consumes at a much slower rate than the biomass feedstocks to be gasified due to the very high fixed carbon fraction of the former. The biochar catalyst, beyond serving as a consuming bed to support the feedstocks and to distribute the plasma heat across the cross section of the reactor, also provides a way to enhance the calorific content of the feedstocks as well as to allow for the flow of the molten inert materials through the porosity of the catalyst bed. The production of the biochar to meet the specifications required for the plasma-enhanced gasification system described herein, comprises both a unique and novel proprietary process, one that is distinct from standard coke catalysts produced from fossil fuels.

[0026a] In another aspect, the present disclosure provides a method for the conversion of organic material by one stage atmospheric plasma enhanced gasification, said method comprising the use of the apparatus and: providing a catalyst bed primarily composed of a biochar material comprising dense solid carbon and ash in a lower section of a reactor; providing one or more successive quantities of said biogenic hydrocarbon waste material from a plurality of directions into an upper part of a lower double bed section of a reactor, said upper plenum section having at least one gas exit port connected to an induction fan, said material forming a bed atop said biochar carbon catalyst bed; providing enhanced heating of said biochar carbon catalyst bed and said biogenic hydrocarbon waste material bed using a plurality of plasma arc torches mounted in said lower double bed section; and introducing into said lower double bed section a gaseous oxidant generated from the integrated oxygen absorber system at atmospheric pressure.

[0027] Other features and advantages of the present disclosure will be readily appreciated, as the same becomes better understood, after reading the subsequent description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1 is an elevation view of a prior art apparatus.

[0029] FIG. 2 is an elevation view of a gasifier used with an embodiment of the present disclosure.

[0030] FIG. 3 is a graph of pressure drop versus diameter size of the feedstock employed according to the present disclosure.

[0031] FIG. 4 is an elevation partial view of a gasifier used with an embodiment of the present disclosure illustrating representative pressure and temperature sensors.

[0032] FIGS. 5A-5C are cross-sectional views of FIG. 4 illustrating location of representative pressure and temperature sensors. FIG. 5D illustrates Process Connection Location (instruments and angle). [Note: all dimensions are in degrees to the centerline of the nozzle, each type of instrument nozzle is spaced equidistantly around the SPGR circumference, and the number of instrument nozzles show is for illustration purposes only.]

[0033] FIG. 6 proves a schematic depicting certain components of one embodiment of an oxygen production module.

[0034] FIG. 7 proves a schematic depicting an integrated oxygen production for IGCC with a reciprocating engine and CO2 capture. Oxygen production module (LCO) as schematically shown earlier in Figure 6 is immersed in a syngas "cooler".

[0035] FIG. 8 provides a flow diagram demonstrating the role of renewable hydrogen produced by the methods described herein in the iron and steel industry.

[0036] FIG. 9 provides a recommended configuration of the inventive plasma-gasification process for cement.

DETAILED DESCRIPTION

[0037] The present invention is described with reference to particular embodiments having various features. It will be apparent to those skilled in the art that various modifications and variations can be made in the practice of the present invention without departing from the scope or spirit of the invention. One skilled in the art will recognize that these features may be used singularly or in any combination based on the