

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
4 September 2008 (04.09.2008)

PCT

(10) International Publication Number  
**WO 2008/104088 A1**

(51) International Patent Classification:

**F23G 5/38** (2006.01) **C02F 11/10** (2006.01)  
**A62D 3/40** (2007.01) **F23G 5/027** (2006.01)  
**C01B 3/02** (2006.01) **B09B 3/00** (2006.01)  
**C01B 31/18** (2006.01) **C10J 3/00** (2006.01)  
**C02F 1/02** (2006.01)

PCT/US2007/070456 5 June 2007 (05.06.2007) US  
60/986,137 7 November 2007 (07.11.2007) US

(71) Applicant (*for all designated States except US*): **PLASCO ENERGY GROUP INC.** [CA/CA]; 1000 Innovation Drive, Suite 400, Kanata, Ontario K2K 3E7 (CA).

(21) International Application Number:

PCT/CA2008/000452

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **TSANGARIS, Andreas** [CA/CA]; 29 Confederation Private, Ottawa, Ontario K1V 9W6 (CA). **BACON, Marc** [CA/CA]; 40, rue Marsolet, Saint-Constant, Québec J5A 1T7 (CA).

(22) International Filing Date:

27 February 2008 (27.02.2008)

(25) Filing Language:

English

(74) Agent: **MBM & CO.**; P.O. Box 809, Station B, Ottawa, Ontario K1P 5P9 (CA).

(26) Publication Language:

English

(30) Priority Data:

60/891,749 27 February 2007 (27.02.2007) US  
60/891,754 27 February 2007 (27.02.2007) US  
60/891,768 27 February 2007 (27.02.2007) US  
60/891,807 27 February 2007 (27.02.2007) US

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC,

[Continued on next page]

(54) Title: A MULTI-ZONE CARBON CONVERSION SYSTEM WITH PLASMA MELTING

(57) Abstract: A multi-zone carbon converter for converting processed feedstock to syngas and slag is provided comprising a chamber comprising a carbon conversion zone in communication with a slag zone for melting ash into molten slag and/or for maintaining slag in a molten state by the application of plasma heat. The carbon conversion zone and the slag zone are separated by the inter-zonal region that comprises an impediment for restricting or limiting the movement of material between the two zones. The inter-zonal region may also provide for the initial melting of the ash into molten slag by affecting the transfer of plasma heat from the slag zone.

WO 2008/104088 A1



LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**(84) Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),

**Published:**

- *with international search report*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

## **A MULTI-CHAMBER CARBON CONVERSION SYSTEM WITH PLASMA MELTING**

### **FIELD OF THE INVENTION**

5

This invention pertains to the field of carbonaceous feedstock gasification and in particular, to a multi-zone carbon converter.

### **BACKGROUND OF THE INVENTION**

10

Gasification is a process that enables the conversion of carbonaceous feedstock, such as municipal solid waste (MSW) or coal, into a combustible gas. The gas can be used to generate electricity, steam or as a basic raw material to produce chemicals and liquid fuels.

15

Possible uses for the gas include: the combustion in a boiler for the production of steam for internal processing and/or other external purposes, or for the generation of electricity through a steam turbine; the combustion directly in a gas turbine or a gas engine for the production of electricity; fuel cells; the production of methanol and other liquid fuels; as a further feedstock for the production of chemicals such as plastics and fertilizers; the extraction of both hydrogen and carbon monoxide as discrete industrial fuel gases; and other industrial applications.

25

Generally, the gasification process consists of feeding carbonaceous feedstock into a heated chamber (the gasifier) along with a controlled and/or limited amount of oxygen and optionally steam. In contrast to incineration or combustion, which operates with excess oxygen to produce CO<sub>2</sub>, H<sub>2</sub>O, SO<sub>x</sub>, and NO<sub>x</sub>, gasification processes produce a raw gas composition comprising CO, H<sub>2</sub>, H<sub>2</sub>S, and NH<sub>3</sub>. After clean-up, the primary gasification products of interest are H<sub>2</sub> and CO.

30

Useful feedstock can include any municipal waste, waste produced by industrial activity and biomedical waste, sewage, sludge, coal, heavy oils, petroleum coke, heavy refinery residuals, refinery wastes, hydrocarbon contaminated soils, biomass, and agricultural wastes, tires, and other hazardous waste. Depending on the origin of

the feedstock, the volatiles may include H<sub>2</sub>O, H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub>, CO, CH<sub>4</sub>, H<sub>2</sub>S, NH<sub>3</sub>, C<sub>2</sub>H<sub>6</sub>, unsaturated hydrocarbons such as acetylenes, olefins, aromatics, tars, hydrocarbon liquids (oils) and char (carbon black and ash).

5 As the feedstock is heated, water is the first constituent to evolve. As the temperature of the dry feedstock increases, pyrolysis takes place. During pyrolysis the feedstock is thermally decomposed to release tars, phenols, and light volatile hydrocarbon gases while the feedstock is converted to char.

10 Char comprises the residual solids consisting of organic and inorganic materials. After pyrolysis, the char has a higher concentration of carbon than the dry feedstock and may serve as a source of activated carbon. In gasifiers operating at a high temperature ( > 1,200 °C) or in systems with a high temperature zone, inorganic mineral matter is fused or vitrified to form a molten glass-like substance called slag.

15

Since the slag is in a fused, vitrified state, it is usually found to be non-hazardous and may be disposed of in a landfill as a non-hazardous material, or sold as an ore, road-bed, or other construction material. It is becoming less desirable to dispose of waste material by incineration because of the extreme waste of fuel in the heating process and the further waste of disposing, as a residual waste, material that can be converted

20 into a useful syngas and solid material.

## SUMMARY OF THE INVENTION

25 An object of the present invention is to provide a multi-zone carbon converter for converting processed feedstock into syngas and slag. In accordance with an aspect of the invention, there is provided a multi-zone carbon converter comprising a carbon conversion zone having one or more processed feedstock inputs, one or more syngas outlets and a heated air input in communication with a slag zone for melting ash

30 and/or for maintaining slag in a molten state comprising a plasma heat source and slag outlet. The carbon conversion and slag zones are separated by an inter-zonal region or inter-zone comprising an impediment for restricting or limiting movement of material between the carbon conversion zone and the slag zone.

In accordance with another aspect of the invention, there is provided a multi-zone carbon converter for converting processed feedstock to syngas and slag comprising a chamber comprising a carbon conversion zone in communication with a slag zone, wherein the carbon conversion zone and the slag zone are separated by an inter-zonal region or inter-zone; the carbon conversion zone comprising a processed feedstock input for receiving processed feedstock from a source, a syngas outlet and a heated air input; the inter-zonal region or inter-zone comprising an impediment to limit the flow of material between the carbon conversion zone and the slag zone by either partial or intermittently occluding the inter-zonal region or inter-zone and optionally, comprising heat transfer elements to provide for initial ash melting; the slag zone comprising a plasma heat source and a slag outlet; wherein the processed feedstock is converted to a syngas and ash in the carbon conversion zone, and the ash is converted into molten slag in the inter-zonal region or inter-zone and/or the slag zone through the application of heat from the plasma heat source.

15

#### BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described, by way of example only, by reference to the attached Figures, wherein:

20

Figure 1 is a block flow diagram showing the different zones of the multi-zone carbon converter in general terms, namely showing the carbon conversion zone in communication with a slag zone for melting ash and/or maintaining slag in a molten state.

25

Figure 2 is a block flow diagram showing the inputs of a multi-zone carbon converter comprising a carbon conversion zone in communication with a slag zone for melting ash and/or for maintaining slag in a molten state in combination with a carbonaceous feedstock gasifier.

30

Figure 3 is a schematic representation of the multi-zone carbon converter in general terms, namely showing the general features of the carbon conversion zone, inter-zonal region or inter-zone and the slag zone.

Figure 4 is a schematic representation of one embodiment of the multi-zone carbon converter in association with a main gasification chamber.

- 5 Figure 5 illustrates a flange chamber design of the multi-zone carbon converter which would facilitate replacement of the impediment and allow for the use of multiple impediment configurations.

10 Figure 6 is a partial longitudinal-section view of one embodiment of the multi-zone carbon converter in which the impediment comprises a plurality of ceramic balls.

Figure 7 is a longitudinal-sectional view of the inter-zonal region or inter-zone and slag zone of one embodiment of the multi-zone carbon converter detailing a domed cogwheel-shaped impediment.

15

Figure 8(A) is a partial longitudinal-section view of one embodiment of the multi-zone carbon converter detailing various ports for process air, a start-up burner port, a port for gas from a hot gas generator, slag outlet and impediment. 8(B) is a cross-sectional view of the embodiment illustrated in 8(A) at level A-A. 8(C) is a top view of the impediment and supporting wedges.

20

Figure 9 is a cross-sectional view of one embodiment of the multi-zone carbon converter in which the impediment comprises a series of interconnected bricks.

- 25 Figure 10 is an illustration of an impediment comprising a grate.

Figure 11 is a longitudinal-sectional view of the inter-zonal region or inter-zone and slag zone of the multi-zone carbon converter of one embodiment of the multi-zone carbon converter.

30

Figure 12 is a longitudinal-sectional view of one embodiment of the multi-zone carbon converter in which the impediment comprises a moving grate. Figures 12(A) and (B) detail moving grate designs.

Figure 13A is a cross-sectional view detailing the ports in the slag zone of one embodiment of the multi-zone carbon converter including oxygen and/or air inputs (O), carbon inputs (C), ports for plasma torches (P) and gas burner port (G). 13B is a partial longitudinal view of the embodiment of the multi-zone carbon converter shown in 13A.

Figure 14 is an enlargement of Figure 13B.

Figure 15 is a partial longitudinal-sectional view of one embodiment of the two zone carbon converter detailing the slag zone with plasma heat deflector.

Figure 16 illustrates a modification of the multi-zone carbon converter in which the slag zone further comprises a weir to form a slag pool to facilitate slag mixing.

Figure 17 is a partial longitudinal-sectional view of one embodiment of the multi-zone carbon converter detailing one embodiment of the slag cooling system including a water spray and drag chain.

Figure 18 is a perspective view of one embodiment of the multi-zone carbon converter detailing processed feedstock inputs and various ports.

Figure 19 is an alternative perspective view of the embodiment of the multi-zone carbon converter illustrated in Figure 18 detailing the processed feedstock input, the syngas outlet and plasma torch.

Figure 20 is a longitudinal-sectional view through the multi-zone carbon converter illustrated in Figure 18 and 19, detailing the impediment between the carbon conversion zone and the slag zone.

Figure 21 details the impediment between the carbon conversion zone and the slag zone of the multi-zone carbon converter illustrated in Figures 18 to 20.

Figure 22 is a cross-sectional view through the air box of the multi-zone carbon converter illustrated in Figures 18 to 21.

Figure 23 is a cross-sectional view through the multi-zone carbon converter of Figures 18 to 22 at torch level detailing the tangentially located air inputs and plasma torch.

- 5     Figure 24 is a cross-sectional view through the multi-zone carbon converter of Figures 18 to 23 at burner level.

Figure 25 illustrates alternative views of the multi-zone carbon converter of Figures 18 to 23.

10

Figure 26 is a perspective view of one embodiment of the multi-zone carbon converter detailing processed feedstock inputs and various ports comprising a grate impediment.

- 15     Figure 27 is an illustration of one embodiment of the multi-zone carbon converter in which the impediment comprises a series of interconnected bricks.

Figure 28 is an illustration of one embodiment of the multi-zone carbon converter in which the impediment comprises a vertically-oriented grate.

20

Figure 29 is an illustration of one embodiment of the multi-zone carbon converter in which the impediment comprises a cogwheel-shaped dome.

- 25     Figure 30 is an illustration of detailing an alternative embodiment of the multi-zone carbon converter.

Figure 31A and B are illustrations of the air flow with one embodiment of the multi-zone carbon converter.

- 30     Figure 32 is an illustration of detailing an alternative embodiment of the multi-zone carbon converter.

Figure 33 is an illustration of detailing an alternative embodiment of the multi-zone carbon converter.



## DETAILED DESCRIPTION OF THE INVENTION

### *Definitions*

5

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

10

As used herein, the term "processed feedstock" includes char, low and ultra-low volatile feedstocks with fixed carbon and ash components, the by-products of a carbonaceous feedstock gasification or pyrolysis process, products obtained from the incomplete combustion of carbonaceous feedstock, or the solids collected in gas conditioning and/or cleanup systems with the heat source inputs from plasma torch.

15

As used herein, the term "syngas" is defined as a gas mixture that contains varying amounts of carbon monoxide and hydrogen generated by the gasification of a carbon containing fuel to a gaseous product with a heating value. Syngas consists primarily of carbon monoxide, carbon dioxide and hydrogen, and has less than half the energy density of natural gas. Syngas is combustible and often used as a fuel source or as an intermediate for the production of other chemicals.

20

"Processed syngas" refers to syngas reformulate or refined using a plasma heat gas refining or reformulating system.

25

As used herein, the term "sensing element" is defined to describe any element of the system configured to sense a characteristic of a process, a process device, a process input or process output, wherein such characteristic may be represented by a characteristic value useable in monitoring, regulating and/or controlling one or more local, regional and/or global processes of the system. Sensing elements considered within the context of the system may include, but are not limited to, sensors, detectors, monitors, analyzers or any combination thereof for the sensing of process, fluid and/or material temperature, pressure, flow, composition and/or other such characteristics, as well as material position and/or disposition at any given point

30

within the system and any operating characteristic of any process device used within the system. It will be appreciated by the person of ordinary skill in the art that the above examples of sensing elements, though each relevant within the context of the system, may not be specifically relevant within the context of the present disclosure, and as such, elements identified herein as sensing elements should not be limited and/or inappropriately construed in light of these examples.

As used herein, the term "response element" is defined to describe any element of the system configured to respond to a sensed characteristic in order to operate a process device operatively associated therewith in accordance with one or more predetermined, computed, fixed and/or adjustable control parameters, wherein the one or more control parameters are defined to provide a desired process result. Response elements considered within the context of the system may include, but are not limited to static, pre-set and/or dynamically variable drivers, power sources, and any other element configurable to impart an action, which may be mechanical, electrical, magnetic, pneumatic, hydraulic or a combination thereof, to a device based on one or more control parameters. Process devices considered within the context of the system, and to which one or more response elements may be operatively coupled, may include, but are not limited to, material and/or feedstock input means, heat sources such as plasma heat sources, additive input means, various gas blowers and/or other such gas circulation devices, various gas flow and/or pressure regulators, and other process devices operable to affect any local, regional and/or global process within the system. It will be appreciated by the person of ordinary skill in the art that the above examples of response elements, though each relevant within the context of the system, may not be specifically relevant within the context of the present disclosure, and as such, elements identified herein as response elements should not be limited and/or inappropriately construed in light of these examples.

### *Overview of the System*

Referring to Figure 1, there is provided a multi-zone carbon converter for the conversion of processed feedstock into a syngas and an inert slag product. The multi-zone carbon converter comprises a multi-zone refractory-lined chamber having one or more input(s) for receiving processed feedstock, one or more gas outlet(s), a slag

outlet, heated air inputs to facilitate the conversion of the processed feedstock into syngas and ash and a plasma heat source to provide the heat necessary to melt the ash into slag and optionally steam or process additive inputs. Optionally, the processed feedstock is pre-treated (homogenized, ground, shredded and/or pulverized) prior to being fed into the converter. In particular, the multi-zone carbon converter comprises a first zone or carbon conversion zone in communication with a second zone or slag zone for melting residual substantially carbon free solid material into molten slag and/or for maintaining slag in a molten state. The carbon conversion zone and the slag zone are separated by the inter-zonal region or inter-zone that comprises an impediment for restricting or limiting the movement of material between the two zones and, in some embodiments, may also provide for the initial melting of the residual substantially carbon free solid material (*i.e.* ash) into molten slag.

The present multi-zone carbon converter is optionally for use in conjunction with a system for generating processed feedstock from carbonaceous feedstocks. For example, the multi-zone carbon converter (10) can receive processed feedstock from a low-temperature gasifier (15) (see Figures 2 and 4). In such configurations, the multi-zone carbon converter may be considered as an extension of the gasifier in that the third stage of the gasification process (*i.e.* carbon conversion) is substantially completed within the multi-zone carbon converter.

Generally, the gasification of the carbonaceous feedstock can be subdivided into three stages, namely, drying, volatilization and char-to-ash (or carbon) conversion.

Stage I: Drying of the Material

The first stage of the gasification process is drying, which occurs mainly between 25°C and 400°C. Some volatilization and some carbon-to-ash conversion may also take place at these lower temperatures.

Stage II: Volatilization of the Material

The second stage of the gasification process is volatilization, which occurs mainly between 400°C and 700°C. A small degree (the remainder) of the drying operation as well as some carbon conversion (char to syngas) will also take place at this temperature.

### Stage III: Char-to-Ash Conversion

The third stage of the gasification process is that of carbon conversion which takes place at a temperature range of between 600°C and 1000°C. A small degree (the remainder) of volatilization will also take place at this temperature. After this stage, the major products are a substantially carbon-free solid residue (ash) and syngas. In order to avoid agglomeration of the ash, the maximum temperature in this region should not exceed about 950°C.

During gasification, in order to increase the yield of the desired syngas products, it is necessary to maximize the conversion of the carbonaceous feedstock into the desired gaseous products. The multi-zone carbon converter therefore provides a system for ensuring the complete conversion of the available carbon remaining in the processed feedstock into a syngas, while also providing for the recovery of the syngas and a slag product. The multi-zone carbon converter therefore also provides for the addition of heated air, and optionally process additives such as steam and/or carbon rich gas and/or carbon, to facilitate the conversion of the carbon to the desired syngas product. The multi-zone carbon converter also provides plasma heat to facilitate the complete conversion of the residual inorganic materials (*i.e.* ash) into a vitrified substance or slag.

The multi-zone carbon converter comprises a multi-zone refractory-lined chamber comprising: one or more processed feedstock inlet(s), a syngas outlet, heated air inlets, a slag outlet, and one or more ports for a plasma heat source such as a plasma torch and optionally one or more process additive inlets or ports. The multi-zone carbon converter also optionally comprises a control subsystem for monitoring operating parameters and adjusting operating conditions within the converter to optimize the conversion reaction. Sensing elements and response elements are integrated within the converter, and the response elements adjust the operating conditions within the converter according to the data obtained from the sensing elements.

The multi-zone carbon converter comprises a first zone or carbon conversion zone in communication with a second zone or slag zone for melting residual solid material

(*i.e.* ash) and/or for maintaining slag in a molten state. The carbon conversion zone and the slag zone are separated by the inter-zonal region or inter-zone that comprises an impediment for guiding and/or restricting the movement of material between the two zones. The inter-zonal region or inter-zone may, optionally also provide for the  
5 initial melting of the residual substantially carbon free solid material (*i.e.* ash) into molten slag and/or facilitate air diffusion and/or mixing.

Figure 3 is a schematic depiction of one embodiment of the multi-zone carbon converter (10). The multi-zone carbon converter (10) comprises processed feedstock  
10 inputs (20) into the carbon conversion zone (11) of the refractory-lined chamber (15), where heated air inputs (35) convert the unreacted carbon in the processed feedstock into a syngas. Residual substantially carbon-free solid material (*i.e.* ash) is subsequently converted into a molten slag material in either the inter-zonal region or inter-zone and/or the slag zone by the direct or indirect (*i.e.* via heat transfer elements)  
15 application of plasma heat. Optionally, the impediment of the inter-zonal region or inter-zone acts as a heat transfer element for transferring the heat of the plasma heat source to the residual solid material (*i.e.* ash) thereby affecting its initial melting. The inter-zonal region or inter-zone may further comprise additional heat transfer element for efficiently transferring the plasma heat. The molten slag material is output from  
20 the slag zone of the multi-zone carbon converter and passed into an optional slag cooling subsystem for cooling. The syngas is output from the converter and is optionally passed back into a main gasification chamber where it is combined with the gaseous products of the main gasification process or is subjected to further downstream processing and/or is stored in a storage tank.

25 The processed feedstock for input into the multi-zone carbon-converter may be from a variety of sources including by-products of a carbonaceous feedstock gasification or pyrolysis process, obtained from the incomplete combustion of carbonaceous feedstock, or the solids collected in gas conditioning and/or cleanup systems with the  
30 heat source inputs from plasma torch.

The multi-zone carbon converter facilitates the production of syngas and slag by sequentially promoting carbon conversion and residual substantially carbon-free solid (*i.e.* ash) melting. This is accomplished by allowing carbon conversion to occur at a

certain temperature range prior to exposing the residual substantially carbon-free solid (*i.e.* ash) to a higher temperature range. The multi-zone carbon converter minimizes or eliminates the amount of carbon trapped in the melt.

- 5 In particular, the carbon conversion process is accomplished by providing the appropriate level of oxygen to the processed feedstock and raising the temperature of the processed feedstock to the level required to convert carbon in the processed feedstock to a syngas by exposing the processed feedstock to the specific environment of the carbon conversion zone. The syngas produced in the conversion process exits  
10 the chamber via a gas outlet.

The resulting syngas may comprise heavy metal and particulate contaminants. Accordingly, in one embodiment, the multi-zone carbon converter optionally further comprises a gas conditioning subsystem for cooling and conditioning the residue gas  
15 as required for downstream applications. Alternatively, the multi-zone carbon converter may be connected to downstream gas condition and/or gas storage systems.

The source of the processed feedstock may be, but is not limited to, a low temperature or high temperature gasifier or pyrolyser, a hopper in which the residue is stored, or  
20 particulate matter separators within a gas conditioning system, for example, a baghouse filter or cyclone. The multi-zone carbon converter may be directly or indirectly connected to the source of the processed feedstock. The processed feedstock is conveyed, continuously or intermittently, from the source of the processed feedstock through appropriately adapted outlets and/or conveyance means  
25 to the processed feedstock inlet of the chamber, as would be known to the skilled worker, according to the requirements of the system and the type of by-product to be removed. Optionally, the processed feedstock is pre-treated prior to input into the chamber. Pre-treatment can include but is not limited to homogenizing, grinding, pulverizing, shredding, source separation or magnetic metal-removal.

30

The molten slag, at a temperature of, for example, about 1200°C to about 1800°C, may continuously be output from the multi-zone carbon converter and thereafter cooled to form a solid slag material. Such slag material may be intended for landfill disposal or may further be broken into aggregates for conventional uses.

Alternatively, the molten slag can be poured into containers to form ingots, bricks tiles or similar construction material. The resulting slag material may also be used as a supplementary cementing material in concrete, in the production of a lightweight aggregate or mineral wool, in the manufacture of foam glass, or in the development of packaging materials.

Accordingly, the multi-zone carbon converter may also include a subsystem for cooling the molten slag to its solid form. The slag cooling subsystem is provided as appropriate to afford the cooled slag product in the desired format.

The multi-zone carbon converter also optionally comprises a control system for managing the carbon conversion and melting process. In particular, the multi-zone carbon converter comprises a control subsystem comprising sensing elements for monitoring operating parameters of the system, and response elements for adjusting operating conditions within the system to manage the conversion process, wherein the response elements adjust the operating conditions within the system according to the data obtained from the sensing elements, thereby promoting efficient and complete carbon conversion and melting. The adjustable operating parameters include, for example, plasma heat rate (power) and position, processed feedstock feed rate, and air and/or steam and/or carbon rich gas and/or carbon-containing gas inputs and/or carbon inputs.

#### *Multi-zone Carbon Converter*

Referring now to Figure 3, the multi-zone carbon converter (10) comprises a refractory-lined chamber (15) having a first end or processed feedstock input end and a second end or slag output end. The converter further comprises a processed feedstock input (20), syngas outlet (25) and slag outlet (30), a plasma heat source (40), hot air inputs (35), one or more additive input(s) (not shown) and, optionally, a control system.

Referring now to Figure 4, which is a schematic depiction of representative multi-zone carbon converters in association with a main gasification chamber. The multi-zone carbon converter (10) comprises processed feedstock inputs (20) into a carbon

conversion zone (11), where heated air inputs (35) convert the processed feedstock into a syngas product and a residual substantially carbon-free solid (*i.e.* ash). The syngas product escapes through the syngas outlet (25). The residual solid material (*i.e.* ash) is melted in the inter-zonal region or inter-zone (12) and/or the slag zone (13) into slag via the indirect (*i.e.* via the use of heat transfer elements) or direct application of plasma heat. The molten slag material is output from the slag zone and passed into an optional slag cooling subsystem for cooling. The syngas output from the chamber is optionally passed back into a main gasification chamber where it is combined with the gaseous products of the main gasification process or is passed to downstream processing and/or storage systems.

#### Design Considerations for the Chamber

The chamber of the multi-zone carbon converter is designed to provide a sealed, insulated space for processing of processed feedstock into syngas and to allow for the passage of syngas to downstream process such as cooling or refining or other and for processing of ash into slag. The design of the chamber promotes the formation of the two zones and reflects the specific requirements of each of these zones. The design may optionally provide for access to the interior of the multi-zone carbon converter for inspection, maintenance and repair. Referring to **Figure 5**, the chamber is optionally a flanged chamber to facilitate the replacement of the individual zones or the inter-zonal region or inter-zone or parts of individual zones.

The multi-zone carbon converter comprises a carbon conversion zone, an inter-zonal region or inter-zone and a slag zone. The carbon conversion zone is adapted to i) input the processed feedstock to be conditioned, ii) input heated air to convert unreacted carbon in the processed feedstock to a syngas having a heating value and substantially carbon-free solid residue, iii) input optional process additives such as steam and/or carbon rich gas, iv) output the syngas and the solid residue. The inter-zonal region or inter-zone is designed to segregate the carbon conversion zone and the slag zone and to regulate the flow of material there between and may optionally provide for the initial melting of the solid residue into slag by effecting the transfer of plasma heat to the solid residue. The slag zone is designed to input heat to condition the substantially carbon-free solid residue from the carbon conversion to form a molten slag material (and optionally convert any residual carbon to gas) or to



maintain molten slag in its molten state, and output the molten slag and where appropriate, gaseous product. Optionally, the slag zone can further comprise or be connected to a slag cooling subsystem to facilitate the solidification of the molten slag. Accordingly, the chamber of the two zone carbon converter is a refractory-lined, generally vertically-oriented chamber comprising a processed feedstock inlet, heated air inlets, a gas outlet, a slag outlet, and a plasma heat source and optionally one or more process additive inlets.

In determining the sizing of the individual zones, the function of the individual zone can be considered. In the carbon conversion zone, as much carbon as possible is being converted to the gas phase. The slag zone functions to melt the ash completely. The carbon conversion zone is sized by the air flow at those quantity the most of carbon being converted meanwhile still in substoichiometric environment with highest possible operating temperature. The cross section area is based on the superficial velocity required so that the operating conditions are in fixed-bed mode instead of fluidization. The slag zone dimension is based on heat balance calculation to maintain at high level temperature to ensure the ash melting with the heat inputs from plasma heat sources.

The multi-zone carbon conversion chamber is designed to ensure that the carbon conversion and ash processing is carried out efficiently and completely, in order to use a minimum amount of energy to effectively complete these processes. Accordingly, factors such as efficient heat transfer, adequate heat temperatures, residence time, molten slag flow, input residue volume and composition, and size and insulation of the chamber are taken into account when designing the chamber. The chamber is also designed to ensure that the processes are carried out in a safe manner. Accordingly, the multi-zone carbon converter is designed to isolate the processing environments from the external environment. Generally, the chamber is designed such that the upstream end, proximal to the processed feedstock input is specifically adapted for the carbon conversion process and the proximal to the slag outlet is specifically adapted for the melting process.

Alternatively, the chamber is designed such that the carbon conversion zone is a centrally located zone and the slag zone encircles the carbon conversion zone. In

such embodiments, the segregation of the carbon conversion zone and the slag zone may be accomplished by elevating the carbon conversion zone in comparison to the slag by use of a sloped floor.

- 5      Optionally, the chamber is shaped to promote or facilitate the separation of the carbon conversion zone and slag zone. Accordingly, in one embodiment, the inter-zonal region or inter-zone forms a constriction of the chamber (See Figure 20).

#### Materials

- 10     The multi-zone carbon conversion chamber is refractory-lined chamber with an internal volume sized to accommodate the appropriate amount of material for the required solids residence time.

The chamber is typically manufactured with multiple layers of materials as are appropriate. For example, the outer layer, or shell, of the chamber is typically steel. Moreover, it may be beneficial to provide one or more insulating layers between the inner refractory layer and the outer steel shell to reduce the temperature of the steel casing. An insulating board around the outer surface of the slag reservoir may also be provided to reduce the temperature of the steel casing. Optionally, a ceramic blanket may be used as an insulator. When room for expansion of the refractory without cracking is required, a compressible material, such as a ceramic blanket, can be used against the steel shell. The insulating materials are selected to provide a shell temperature high enough to avoid acid gas condensation if such an issue is relevant, but not so high as to compromise the integrity of the outer shell.

- 25     The refractory protects the chamber from the high temperature and corrosive gases and minimizes unnecessary loss of heat from the process. The refractory material can be a conventional refractory material well-known to those skilled in the art and which is suitable for use for a high temperature *e.g.*, a temperature of about 1100°C to 1800°C), un-pressurized reaction. When choosing a refractory system factors to be considered include internal temperature, abrasion; erosion and corrosion; desired heat conservation/limitation of temperature of the external vessel; desired life of the refractory. Examples of appropriate refractory material include high temperature fired ceramics, *i.e.*, aluminum oxide, aluminum nitride, aluminum silicate boron

nitride, zirconium phosphate, glass ceramics and high alumina brick containing principally, silica, alumina, chromia and titania. To further protect the chamber from corrosive gases the chamber is, optionally, partially or fully lined with a protective membrane. Such membranes are known in the art and, as such, a worker skilled in the art would readily be able to identify appropriate membranes based on the requirements of the system and, for example, include Sauereisen High Temperature Membrane No 49.

In one embodiment, the refractory is a multilayer design with a high density layer on the inside to resist the high temperature, abrasion, erosion and corrosion. Outside the high density material is a lower density material with lower resistance properties but higher insulation factor. Optionally, outside this layer is a very low density foam board material with very high insulation factor and can be used because it will not be exposed to abrasion or erosion. Appropriate materials for use in a multilayer refractory are well known in the art.

In one embodiment, the multilayer refractory comprises an internally oriented chromia layer, a middle alumina layer and an outer insboard layer.

Optionally, the refractory in the individual zones and regions may be specifically adapted for the environment within that particular area of the chamber. For example, the bottom part of the chamber may have a thicker refractory where the working temperature is higher. In addition, the refractory of the slag zone may be adapted to withstand higher temperatures and be designed to limit slag penetration into the refractory thereby reduce corrosion of the refractory.

The wall of the chamber can optionally incorporate supports for the refractory lining or refractory anchors. Appropriate refractory supports and anchors are known in the art.

Due to the severe operating conditions, it is anticipated that the refractory may require periodic maintenance. Accordingly, in one embodiment, the chamber is flanged such that separable upper and lower portions are provided, wherein the chamber lower portion (where the reservoir is located) is removable from the chamber upper portion.

In one embodiment, the chamber is suspended from a support structure such that the lower portion can be dropped away from the upper portion to facilitate maintenance. This embodiment provides for removing the lower portion without disturbing any connections between the chamber upper portion and upstream or downstream components of the system.

#### *Carbon Conversion Zone*

The carbon conversion process is accomplished by raising the temperature of the processed feedstock to the level required to convert carbon in the processed feedstock to a syngas by exposing the processed feedstock to the specific environment of the carbon conversion zone. The syngas produced in the conversion process exits the chamber via a gas outlet. In one embodiment, the syngas is passed back into a gasification chamber, where it combines with the gases produced during the main gasification process.

Referring to **Figure 4**, the carbon conversion zone (11) comprises one or more input(s) (20) for receiving processed feedstock, one or more syngas outlet(s) (25) and is in communication via the inter-zonal region or inter-zone (12) with the slag zone (13).

The carbon conversion zone (11) is provided with heated air inlets (35) to provide the required temperature for converting any remaining volatiles and carbon to a syngas. The chamber is also designed to ensure highly efficient exposure of the residue to the heated air to minimize the amount of sensible heat that is lost via the product gas. Therefore, the position and orientation of the heated air inlets are additional factors to be considered in the design of the carbon conversion zone.

#### Processed Feedstock Input

The multi-zone carbon converter comprises a processed feedstock input in association with the processed feedstock inlet of the converter chamber. The processed feedstock inlet is adapted to receive the processed feedstock into the carbon conversion zone of the chamber. The input of processed feedstock into the chamber may be passive (*i.e.* by gravity) or active. Optionally, the processed feedstock input actively conveys the

processed feedstock from a source to the inlet of the converter chamber. Appropriate active conveyance mechanisms are known in the art and include double locked-hoppers, screw conveyors, drag chains, pneumatically pushed and other means known in the art.

5

Processed feedstock entering the chamber may come from one or multiple sources. Sources of the processed feedstock may include, but are not limited to, a low temperature or high temperature gasifier, a hopper in which the residue of a gasification process is stored, or upstream gas conditioning systems, for example, a baghouse filter or fly ash from cyclones.

Where the processed feedstock is provided in more than one input stream, or from more than one source, the different streams may each be passed into the chamber through a dedicated processed feedstock inlet, or they may be combined prior to introduction into the chamber. In the latter embodiment, there is provided one processed feedstock inlet through which all processed feedstock are provided. Accordingly, the chamber may comprise a common inlet or multiple inlets.

The source of the processed feedstock may be provided in direct communication with the multi-zone carbon converter chamber, *i.e.*, each processed feedstock input is fed directly from the source into the chamber. Alternatively, the source may be provided in indirect communication with the chamber, wherein the residue inputs are conveyed from the source into the chamber via a system of conveyor means.

Where the multi-zone carbon converter chamber is indirectly connected to the source of the processed feedstock, the processed feedstock input comprises one or more means for conveying the processed feedstock from the source into the chamber. For example, the processed feedstock may include a single screw conveyor or a series of screw conveyors, belts, rams, plows, rotating arms, rotating chains, traveling grates and pusher rams.

The multi-zone carbon converter chamber is optionally provided with an air lock in association with the processed feedstock input. This optional air lock may be located

to provide a barrier between the source of the processed feedstock (and the ambient air to guard against excessive air ingestion )and the interior of the chamber.

5 The processed feedstock input optionally includes a control mechanism such that the input rate of the processed feedstock can be controlled to ensure optimal carbon conversion and melting and homogenization of the residual material.

10 The processed feedstock input optionally includes or is optionally connected to a pre-treatment module. Pre-treatment includes treatments that homogenize or reduce the size of processed feedstock particles and include, for example, grinding, pulverizing and homogenizing. Appropriate grinders, pulverizers and homogenizers are known in the art.

#### Carbon Conversion Zone Heating System

15 The carbon conversion process requires heat. Heat addition can occur directly by partial oxidation of the processed feedstock ( i.e. by the exothermic reaction of oxygen in the air inputs with carbon and volatiles present in the processed feedstock) or indirectly by the use of one or more heat sources know in the art.

20 The heat required to convert the unreacted carbon in processed feedstock is provided (at least partially) through the use of heated air inputs.

The hot air can be supplied from, for example, air boxes, air heaters or heat exchangers, all of which are known in the art.

25 In one embodiment, hot air is feed into the carbon conversion zone by air feed and distribution system with inputs proximal to the inter-zonal region or inter-zone. Appropriate air feed and distribution systems are known in the art and include air boxes for each step level from which hot air can pass through perforations in the wall  
30 of the chamber or via air nozzles or spargers.

Additional or supplemental heating as may be required can be provided by one or more heating means known in the art including, but not limited to, a gas burner.

In one embodiment, the additional heat source can be circulating hot sand.

In one embodiment, the additional heat source can be an electrical heater or electrical heating elements.

5

In order to facilitate initial start up of the multi-zone carbon converter, the chamber can include access ports sized to accommodate various conventional burners, for example natural gas, oil/gas or propane burners, to pre-heat the chamber. Also, wood/biomass sources, engine exhausts, electric heaters could be used to preheat the chamber.

10

#### Process Additive Inputs

Process additives may optionally be added to the carbon conversion zone to facilitate efficient conversion of processed feedstock into syngas. Steam input can be used to ensure sufficient free oxygen and hydrogen to maximize the conversion of decomposed elements of the input processed feedstock into product gas and/or non-hazardous compounds. Air input can be used to assist in processing chemistry balancing to maximize carbon conversion to a fuel gas (minimize free carbon) and to maintain the optimum processing temperatures while minimizing the cost of input heat. In addition, oxygen and/or ozone may be inputted through process additive ports into the carbon conversion zone.

15

20

Optionally, other additives may be used to optimize the carbon conversion process and thereby improve emissions.

25

Optionally, carbon-rich gas can be used as a process additive.

30

The carbon conversion zone, therefore, can include one or more process additive inputs. These include inputs for steam injection and/or air injection and/or carbon-rich gas. The steam inputs can be strategically located to direct steam into high temperature regions and into the product gas mass just prior to its exit from the converter. The air inputs can be strategically located in and around the chamber to ensure full coverage of process additives into the carbon conversion zone.

In one embodiment, the process additive inputs are located proximal to the inter-zonal region or inter-zone.

5 In one embodiment, the process additive inputs provide diffuse, low velocity input of additives.

In embodiments in which hot air is used to heat the chamber additional air/oxygen injection inputs may optionally be provided.

#### 10 *Inter-Zonal Region or Inter-Zone*

The inter-zonal region or inter-zone functions to substantially spatially segregate the carbon conversion zone from the slag zone and optionally provides for the initial melting of the residual solid material (*i.e.* ash) of carbon conversion by effectively  
15 transferring plasma heat to the residual solid material. The inter-zonal region or inter-zone further provides a conduit or connection between the two zones. The inter-zonal region or inter-zone comprises an impediment that limits or regulates the movement of material between the carbon conversion and slag zone by either partial or intermittently occluding the inter-zonal region or inter-zone, impedes excessive  
20 migration of unconverted carbon into the melt and may optionally further comprise heat transfer elements.

Referring to Figure 6, in one embodiment, the inter-zonal may optionally be substantially contiguous with the slag zone.

25

#### Impediment

The impediment limits or regulates the movement of material between the carbon conversion and slag zone by either partial or intermittently occluding the inter-zonal region or inter-zone and may optionally further provide for heat transfer.

30

The impediment is mounted within the inter-zonal region or inter-zone and can be of various shapes or designs, including but not limited to dome shaped, pyramidal shaped, grates, moving grates, brick grate; plurality of ceramic balls, plurality of



tubes; cogwheel-shaped *etc.* The shape and size of the impediment may in part be dictated by shape and orientation of the chamber.

5 The impediment and any necessary mounting elements must be able to effectively operate in the harsh conditions of the multi-zone carbon converter and in particular must be able to operate at high temperatures. Accordingly, the impediment is constructed of materials designed to withstand high temperature. Optionally, the impediment may be refractory-lined or manufactured from solid refractory.

10 Referring to **Figures 6 to 10**, which detail various alternative, non-limiting impediments.

In one embodiment as illustrated in **Figure 6**, the impediment comprises a plurality of ceramic balls.

15 In the embodiment as illustrated in **Figure 7**, the impediment comprises a cogwheel-shaped refractory dome.

In one embodiment as illustrated in **Figure 8**, the impediment is a solid refractory dome (145) mounted by wedge-shaped mounting bricks (150) in the inter-zonal region. The solid refractory dome is sized such that there is a gap (155) between the outside edge of the dome and the inner wall of the chamber. Optionally, the refractory dome further comprises a plurality of holes (160).

20 In the illustrated embodiment, an optional plurality of alumina or ceramic balls (165) between 20 to 100mm in diameter rest on top of the refractory dome to form a bed and provide for diffusion of heated air and to promote the transfer of plasma heat to the ash to initially melt the ash into slag. In this embodiment, as the ash melts it transits the inter-zonal region through the gap (160) between the outside edge of the dome (145) and the inner wall of the chamber and into the slag zone.

25 Referring to **Figure 9**, the impediment comprises a solid refractory brick grate. The refractory brick grate (245) is provided with gaps (255) between the individual bricks

to allow for communication between the carbon conversion zone and the slag zone via the inter-zonal region.

Referring to **Figure 10**, the impediment comprises a grate structure manufactured from refractory-lined tubes (345) mounted within a mounting ring (350).

Referring to **Figure 12**, the impediment comprises a moving grate.

#### Heat transfer elements and Diffusion Elements

Optionally, the inter-zonal region may further comprise heat transfer or diffusion elements to facilitate the transfer of plasma heat to the ash. Heat transfer elements are known in the art and include ceramic balls, pebbles, bricks.

In one embodiment, the heat transfer element comprises plurality of alumina or ceramic balls (165) between 20 to 100mm in diameter rest on top of the refractory dome to form a bed and provide for diffusion of heated air and to promote the transfer of plasma heat to the ash to initial melt the ash into slag.

Optionally, the impediment may be or comprise the heat transfer element.

#### Optional Heating Elements

Optionally, the inter-zonal region or inter-zone may be equipped with a source heat. Appropriate sources of heat include an air tuyere, an electrical heater or electrical heating elements, burners or sources of plasma heat including plasma torches.

The optional plasma torches can be placed in the inter-zonal region and/or at the carbon-conversion zone / inter-zonal region interface and/or at the inter-zonal region / slag zone interface

Optionally, any carbon remaining in the ash is converted to a syngas by the application of plasma heat in inter-zonal region or inter-zone.

Accordingly, the chamber wall of the inter-zonal region can include access ports sized to accommodate various sources of heat.

*Slag Zone*

5 The melting process is accomplished by raising the temperature of the residual substantially carbon-free solid material (ash) to the level required to melt the remaining residue and occurs within the inter-zonal region and/or the slag zone. The heat required for the melting process is provided by one or more plasma heat sources. This heat may be directly applied or indirectly applied via heat transfer elements. The plasma heat will also serve to convert any small amounts of carbon remaining in the residue after the carbon conversion by the heated air inputs. Additional or supplemental heating as may be required can be provided by one or more heating means known in the art including, but not limited to, induction heating or joule heating.

15 The slag zone is provided with a plasma heat source that meets the required temperature for heating the ash (directly or indirectly) to levels required to melt and homogenize the residual solid to provide a molten slag at a temperature sufficient to flow out of the multi-zone carbon converter. Optionally, any carbon remaining in the ash is converted to a syngas. The slag zone is also designed to ensure highly efficient heat transfer between the plasma gases and the residue or slag, to minimize the amount of sensible heat that is lost. Therefore, the type of plasma heat source used, as well as the position and orientation, of the plasma heating means are additional factors to be considered in the design of the slag zone.

25 The slag zone is also designed to ensure that the residue residence time is sufficient to bring the residue up to an adequate temperature to fully melt and homogenize the residual inorganic materials.

30 Referring to Figures 13 and 16, optionally, the slag zone is provided with a reservoir in which the residue accumulates while being heated by the plasma heat source. The reservoir also allows mixing of the solid and molten materials during the conditioning process. Sufficient residence time and adequate mixing ensures that the conditioning process is completely carried out, and that the resulting slag has the desired composition.

The slag zone may be tapered towards the slag outlet or have a sloped floor to facilitate escape of molten slag.

- 5 The slag zone is designed for continuous output of the molten slag material. Continuous slag removal allows the conditioning process to be carried out on a continual basis, wherein the residue to be conditioned may be continuously input and processed by the plasma heat, without interruption as would be required for periodic slag removal.

10

In one embodiment, continuous slag exhaust is achieved by using a reservoir bounded on one side by a weir (33) that allows the slag pool to accumulate until it exceeds a certain level, at which point the molten slag runs over the weir and out of the chamber.

15

- Where the processed feedstock being conditioned contains a significant amount of metal, and the slag zone comprises a reservoir bounded by a weir, the metals, due to their higher melting temperature and density, typically accumulate in the reservoir until such time as they are removed. Accordingly, in one embodiment of the multi-  
20 zone converter, the reservoir is optionally provided with a metal tap port, whereby the tap port is plugged with a soft refractory paste, through which a hole may be periodically opened using the heat from an oxygen lance. Once the tap port has been opened and the chamber temperature has been raised sufficiently to melt the accumulated metals, the molten metals are tapped off from the bottom of the  
25 reservoir. The outlet is resealed by placing refractory or other suitable material into the hole.

- Due to the very high temperatures needed to condition the ash, and particularly to melt any metals that may be present, the chamber wall and floor in the slag zone may  
30 optionally be lined with a refractory material that will be subjected to very severe operational demands. The selection of appropriate materials for the design of the slag zone is made according to a number of criteria, such as the operating temperature that will be achieved during typical residue conditioning processes, resistance to thermal shock, and resistance to abrasion and erosion/corrosion due to the molten slag and/or

hot gases that are generated during the melting process. The porosity of the material may be considered when choosing material for the slag zone.

5 The slag zone may also include one or more ports to accommodate additional structural elements or instruments that may optionally be required. In one embodiment, the port may be a viewport that optionally includes a closed circuit television to maintain operator full visibility of aspects of the ash processing, including monitoring of the slag outlet for formation of blockages. The chamber may also include service ports to allow for entry or access into the chamber for  
10 maintenance and repair. Such ports are known in the art and can include sealable port holes of various sizes.

#### Plasma Heat

15 The slag zone employs one or more plasma heating sources to convert the ash material produced by the carbon conversion processes. The plasma heat sources may be movable, fixed or a combination thereof.

The plasma heat sources may comprise a variety of commercially available plasma  
20 torches that provide suitably high temperature gases for sustained periods at the point of application. In general, such plasma torches are available in sizes from about 100 kW to over 6 MW in output power. The plasma torch can employ one or a combination of suitable working gases. Examples of suitable working gases include, but are not limited to, air, argon, helium, neon, hydrogen, methane, ammonia, carbon  
25 monoxide, oxygen, nitrogen, and carbon dioxide. In one embodiment of the present invention, the plasma heating means is continuously operating so as to produce a temperature in excess of about 900°C to about 1800°C as required for converting the residue material to the inert slag product.

30 In this respect, a number of alternative plasma technologies are suitable for use in the slag zone. For example, it is understood that transferred arc and non-transferred arc torches (both AC and DC), using appropriately selected electrode materials, may be employed. It is also understood that inductively coupled plasma torches (ICP) may

also be employed. Selection of an appropriate plasma heat source is within the ordinary skills of a worker in the art.

5 The use of transferred arc torches instead of non-transferred arc torches may improve the efficiency of the residue conditioning process due to their higher electrical to thermal efficiency, as well as the higher heat transfer efficiency between the hot plasma gases and the material being melted because the arc passes directly through the melt. Where transferred arc torches are used, it is necessary to ensure that the slag zone is electrically isolated since the slag zone outer shell will be electrically  
10 connected to the power supply.

In one embodiment, the plasma heat source is a DC non-transferred arc torch.

15 In one embodiment, the plasma torch is a graphite torch.

In one embodiment of the multi-zone carbon converter, the one or more plasma heat sources are positioned to optimize the conversion of the residue material to inert slag. The position of the plasma heat source(s) is selected according to the design of the residue conditioning chamber. For example, where a single plasma heat source is  
20 employed, the plasma heat source may be mounted in the top of the chamber and disposed in a position relative to the slag pool collecting at the bottom of the chamber to ensure sufficient heat exposure to melt the residue material and force the slag to flow. In one embodiment, the plasma heat source is a plasma torch vertically mounted in the top of the chamber.

25 All plasma heat sources are controllable for power and optionally (where movable heat sources are used) position. In one embodiment, the plasma heat rate is varied to accommodate varying residue input rate. The plasma heat rate can also be varied to accommodate varying residue melting temperature properties.

30 The plasma heat sources may be operated on a continuous or non-continuous basis at the discretion of the operator to accommodate varying residue input rate and melting temperature properties.

Optionally, the slag zone may be equipped with a deflector (61) to deflect or direct the plasma heat (see Figures 15 and 16).

#### Process Additives

- 5 Process additives may optionally be added to the slag zone including steam, air, carbon and/or carbon-rich gas and/or oxygen-rich gas and/or bag ash. Accordingly, the slag zone may be equipped with various inputs and/or the chamber at the slag zone may further comprising a number of ports for these inputs.

#### 10 Slag Output

- The slag zone comprises a slag output. The slag output includes an outlet on the chamber through which molten slag is exhausted. The outlet is typically located at or near the bottom of the chamber to facilitate the gravity flow of the molten slag pool  
15 out of the chamber. The slag output also optionally includes a slag cooling subsystem to facilitate the cooling of the molten slag to its solid form. Such a cooling subsystem can for example include a pool of water or water spray.

- The molten slag can be extracted in a continuous manner throughout the full duration  
20 of processing. The molten slag can be cooled and collected in a variety of ways that will be apparent to a person skilled in the art to form a dense, non-leachable, solid slag.

- Optionally, as the ash is conditioned by the plasma heat, the resulting molten slag  
25 accumulates in a reservoir. The resulting molten slag is extracted in a continuous manner, *i.e.*, as the volume of molten slag in the reservoir increases, it passes over a weir and exits the conditioning chamber through an outlet.

- Continuous extraction embodiments are particularly suitable for systems that are  
30 designed to operate on a continuous basis.

In one embodiment, the slag output means also comprises a slag cooling subsystem for cooling the molten slag to provide a solid slag product. In one embodiment, the molten slag is poured into a quench water bath (78). The water bath provides an

efficient system for cooling the slag and causing it to shatter into granules suitable for commercial uses, such as for the manufacture of concrete or for road building. The water bath may also provide a seal to the environment in the form of a shroud that extends from the base of the slag chamber down into the water bath, thereby  
5 providing a barrier preventing outside gases from entering the residue conditioning chamber. The solid slag product may be removed from the water bath by a conveyor system. Alternatively, the slag cooling subsystem may comprise a water spray.

In one embodiment of the slag cooling subsystem, the molten slag is dropped into a  
10 thick walled steel catch container for cooling. In one embodiment, the molten slag is received in an environmentally sealed bed of silica sand or into moulds to provide solid slag suitable for small scale processing or for testing certain parameters whenever such testing is performed. The small moulds can be control cooled in a preheated oven.

15 In one embodiment of the slag cooling subsystem, the molten slag is converted to a commercial product such as glass wool.

### Control

20 In one embodiment of the multi-zone carbon converter, a control system may be provided to control one or more processes implemented in, and/or by, multi-zone carbon converter. In general, the control system would monitor and regulate the different processes to ensure the efficient and complete conversion of the processed  
25 feedstock into a syngas product and efficient and melting of the residual solid (*i.e* ash) into slag.

The control system comprises one or more sensing elements for real-time monitoring of operating parameters of the system; and one or more response elements for  
30 adjusting operating conditions within the system to optimize the conversion reaction, wherein the sensing elements and the response elements are integrated within the system, and wherein the response elements adjust the operating conditions within the system according to the data obtained from the sensing elements.



*Control Elements*

Sensing elements contemplated within the present context can include, but are not limited to, means for monitoring operational parameters such as gas flow, temperature  
5 and pressure at various locations within the system, as well as means for analyzing the chemical composition of the syngas product.

The data obtained from the sensing elements is used to determine if any adjustments to the conditions and operating parameters within the multi-zone carbon converter are  
10 required to optimize the efficiency of the processes and the composition of the product syngas. Ongoing adjustments to the reactants (for example, rate of processed feedstock addition, input of heated air and/or steam), as well as to certain operating conditions, such as pressure within various components within the system, enable this process to be conducted under conditions that enable the consistent and efficient  
15 production of the syngas.

The control system can be designed and configured with the objective of optimizing the efficiency of the conversion process and to mitigate environmental impacts caused by the process. The control system can also be designed to operate the multi-zone  
20 carbon converter under continuous operating conditions.

The following operational parameters may be intermittently or continuously monitored by the sensing elements, and the data obtained are used to determine whether the system is operating within the optimal set point, and whether, for  
25 example, there needs to be more power delivered by the torches, more air or steam injected into the system, or if the processed feedstock input rate needs to be adjusted.

Temperature

In one embodiment, the control system comprises means to monitor the temperature  
30 at sites located throughout the multi-zone carbon converter as required for example, inside the carbon conversion zone, inter-zonal region, or slag zone. The means for monitoring the temperature may be thermocouples or optical thermometers installed at locations in the system as required.

Means for monitoring the temperature of the hot syngas product may also be located at the syngas outlet of the carbon conversion zone.

#### System Pressure

5 In one embodiment, the control system comprises means to monitor the pressure at locations throughout the multi-zone carbon converter. These pressure monitoring means may include pressure sensors such as pressure transducers, pressure transmitters or pressure taps located anywhere in the system, for example, on a vertical wall of the chamber.

10

#### Gas Flow Rate

In one embodiment, the control system comprises means to monitor the rate of syngas flow. Fluctuations in the gas flow may be the result of non-homogeneous conditions (e.g. torch malfunction or interruptions in the material feed), therefore if fluctuations  
15 in gas flow persist, the system may be shut down until the problem is solved.

#### Gas Composition

In one embodiment, the control system comprises means to monitor the composition of the syngas product. The gases produced during the conversion process can be  
20 sampled and analyzed using methods well known to the skilled worker.

In one embodiment, the syngas composition is monitored by means of a gas monitor, which is used to determine the chemical composition of the syngas, for example, the hydrogen, carbon monoxide and carbon dioxide content of the synthesis gas. In one  
25 embodiment, the chemical composition of the syngas product is monitored through gas chromatography (GC) analysis. Sample points for these analyses can be located throughout the system. In one embodiment, the gas composition is monitored using a Fourier Transform Infrared (FTIR) Analyser, which measures the infrared spectrum of the gas.

30

Although high temperature gas analysis means exist, one skilled in the art can appreciate that it may be required to cool the gas prior to analyzing its composition, depending upon the type of system used for gas analysis.

*Response Elements*

Response elements contemplated within the present context can include, but are not limited to, various control elements operatively coupled to process-related devices  
5 configured to affect a given process by adjustment of a given control parameter related thereto. For instance, process devices operable within the present context via one or more response elements, may include, but are not limited to, means for adjusting various operational parameters such as the rate of addition of the processed feedstock, air and/or steam, as well as operating conditions, such as power to the torch  
10 and torch position.

Plasma Heat Source

The present carbon converter uses the controllability of plasma heat to ensure the complete melting and vitrification of ash to slag.  
15

In one embodiment of the invention, the control system comprises means to adjust the power, and optionally the position, of the plasma heat source. For example, when the temperature of the melt is too low, the control system may command an increase in the power rating of the plasma heat source; conversely, when the temperature of the  
20 chamber is too high, the control system may command a drop in the power rating of the plasma heat source.

In one embodiment, the power of the torch is maintained at a level that is proportional to the rate of the residue addition, i.e., an increase in the residue feed rate results in an  
25 increase in the torch power. The torch power can also be adjusted to react to changes in the characteristics and composition of the residue, for example, with respect to its melting properties such as temperature, specific heat capacity, and heat of fusion.

In one embodiment, the position of the plasma heat source is adjustable to ensure  
30 complete coverage of the melt pool, and the elimination of areas of incompletely reacted materials.

The Rate of Processed Feedstock Addition

In one embodiment of the invention, the control system comprises means to adjust the supply rate of processed feedstock to the carbon conversion zone. The processed feedstock may be added in a continuous manner, for example, by using a rotating screw or auger mechanism, or it can be added in a discontinuous fashion.

5

In each case, where the processed feedstock input means comprises a series of pusher rams, the control system may optionally employ limit switches or other means of travel control such as computer controlled variable speed motor drives to control the length, speed and/or frequency of the ram stroke so that the amount of material fed  
10 into the respective chamber with each stroke can be controlled. Where the input means comprises one or more screw conveyors, the rate of addition of the material to the carbon conversion zone may be controlled by adjusting the conveyor speed via drive motor variable frequency drives.

15 The input rates are adjusted as required to ensure acceptable control over the processed feedstock conversion steps, thereby preventing the conveyance of incompletely converted materials out of the carbon conversion zone.

#### Addition of Process Additives

20 In one embodiment of the invention, the control system comprises means to adjust the rate and/or amounts of air inputs into carbon conversion and/or slag zone or the inputs of other process additives including carbon and steam.

Heated air inputs may be provided as required to maintain optimum processed  
25 feedstock conversion temperatures.

In one embodiment, the control system comprises process control means for adjusting the process additives based on data obtained from monitoring and analyzing the composition of the syngas. The gas composition data may be obtained on a  
30 continuous basis, thereby allowing the adjustments to additive inputs such as air and steam to be made on a real-time basis. The type and quantity of the process additives are very carefully selected to optimize the chemical composition of the syngas while maintaining adherence to regulatory authority emission limits and minimizing operating costs.

## EXAMPLES

### 5 Example 1

Referring to **Figures 8, 11, 18 to 25**, the multi-zone carbon converter (110) is zonally segregated by an interzonal region (112) into an upper carbon conversion zone (111) and lower slag melting zone (113). The carbon conversion zone (111) is maintained  
10 at a temperature of about 950°C to about 1100°C and the slag melting zone is maintained at a temperature of about 1350°C to about 1600°C.

Referring to **Figures 8, 11, 18 to 25**, in the illustrated embodiment the multi-zone carbon converter (110) comprises a refractory-lined vertically-oriented chamber (115)  
15 having a processed feedstock input (120), gas outlet (125), a slag outlet (130), and zone-specific heating system (*i.e.* a system that can establish two temperature zones) comprising an air box (135) and plasma torch (140). If necessary, the processed feedstock input is optionally equipped with a grinder (**not shown**) to homogenize the size of the inputted material.

20 The chamber (115) is a refractory-lined steel weldment having a substantially cylindrical shape with a roof and has a length-to-diameter ratio of about 3.6:1 at its widest point. The diameter of the chamber is narrowed in the inter-zonal region at throat and further tapers towards the slag outlet. The chamber is constructed in  
25 segments to facilitate the replacement of components including those within the inter-zonal region.

The refractory comprises three layers, the internal layer is: chromia-alumina type castable, for high temperature resistance, the middle layer and outer layer are plicaste  
30 insulating castable refractory and insulboard respectfully. For the lower part of chamber vessel, the refractory is thicker due to the higher operating temperature, 190mm shamrock 493, 115mm plicast LWI-28 and 76 mm insboard 2300HD and 25mm durablanket are applied. The refractory at the top section is composed by 190mm Plicast Hymor 2800, 114mm IFB and 100 mm Legrit super lite CD.

Referring to **Figure 22**, heated air is introduced into the carbon conversion zone via an air box (135) located proximal to the downstream end of this zone. The air feed to the air box is controllable allowing for regulation of the conversion process. The air flow rate is controlled by the feed/air ratio and operating temperature change. Optionally, steam may be injected into the carbon conversion zone via the steam injection ports (136).

Referring to **Figure 21**, the carbon conversion zone (111) tapers to the narrowed inter-zonal region (112). The inter-zonal region comprises a physical impediment (145) to guide the flow of material from the carbon conversion zone to the slag zone. Referring to Figures 8 and 11, the physical impediment comprises a solid pre-cast refractory dome (145) mounted in the inter-zonal region via four wedge-shaped refractory bricks (150). The refractory dome is sized to provide a gap (155) or space between the internal wall of the multi-zone carbon converter and the dome thereby allowing for transfer of material between zones. The gap is sized appropriately to allow molten slag to pass through. Optionally, the refractory dome can have a plurality of holes (151).

A plurality of alumina or ceramic balls (165) between 20 to 100mm in diameter rest on top of the refractory dome to form a bed and provide for diffusion of heated air and to promote the transfer of plasma heat to the ash to initially melt the ash into slag in the inter-zonal region. In this embodiment, as the ash melts it transits the inter-zonal region through the gap (155) between the outside edge of the dome and the inner wall of the chamber and into the slag zone.

Located downstream of the inter-zonal region is the slag zone (113). The slag zone (113) is a refractory-lined cylinder having a single conically shaped slag outlet (130).

The slag zone comprises various ports including a plasma torch port, burner port to accommodate a burner (139) to pre-heat the chamber, and ports for various process additives including hot air and carbon and/or bag ash. Referring to **Figure 23**, the slag melting zone is equipped with a plasma torch (140) and tangentially mount air nozzle (141) with pneumatic conveyor gas and hot air injection nozzles. The hot air,

carbon and/or bag ash and plasma torch form a hot gas generator (HGG) and achieve high temperature gas ( $>1600^{\circ}\text{C}$ ) to promote ash melting. The plasma torch is rated at 300kW, water cooled, copper electrode, NTAT, DC plasma. Optionally, carbon and/or bag ash can be injected using carbon input or through the air nozzles.

5 Referring to **Figure 24**, the chamber further comprises a port to accommodate a burner (139) to facilitate start-up.

Referring to **Figure 25**, upon exiting the slag zone the molten slag passes through a water spray (113) thereby solidifying the slag into pieces. The pieces of slag are

10 removed via a drag chain assembly (114).

The plasma torch (140) is mounted on a sliding mechanism that can move the torch (140) into and out of the slag melting zone. Optionally, the torch can be brought closer for higher heat intensity. The torch (140) is sealed to the chamber by means of

15 a sealing gland. This gland is sealed against a gate valve, which is, in turn, mounted on and sealed to the vessel. To remove a torch (140), it is pulled out of the chamber (115) by the slide mechanism. Initial movement of the slide disables the high voltage torch power supply for safety purposes. The gate valve shuts automatically when the torch (140) has retracted past the valve and the coolant circulation is stopped. The

20 hoses and cable are disconnected from the torch (140), the gland is released from the gate valve and the torch (140) is lifted away by a hoist.

Replacement of a torch (140) is done using the reverse of the above procedure; the slide mechanism can be adjusted to permit variation of the insertion depth of the torch

25 (140).

The gate valve is operated mechanically so that operation is automatic. A pneumatic actuator is used to automatically withdraw the torch in the event of cooling system failure. Compressed air for operating the actuator is supplied from a dedicated air

30 reservoir so that power is always available even in the event of electrical power failure. The same air reservoir provides the air for the gate valve. An electrically interlocked cover is used a further safety feature by preventing access to the high voltage torch connections.

Thermocouples are positioned at various locations with the carbon converter such that the temperature within the zones is maintained at pre-determined temperature and if it falls below this temperature power to the plasma torches or air injection is increased

5    Example 2

The general structure and design of the multi-zone carbon converter is as described above, in that the carbon conversion zone and slag zone are substantially the same as that described in Example 1. Referring to **Figures 10 and 26**, in the illustrated  
10    embodiment the multi-zone carbon converter (310) comprises a refractory-lined vertically-oriented chamber (315) having a processed feedstock input (**not shown**), syngas outlet (325), a slag outlet (330), and zone-specific heating system (*i.e.* a system that can establish two temperature zones) comprising an air inlets (**not shown**) and plasma torch (340).

15    Referring to **Figures 10 and 26**, the inter-zonal region comprises a physical impediment to regulate the flow of material from the carbon conversion zone to the slag zone. In the instant embodiment, the physical impediment comprises a series of substantially parallel refractory line tubes (345) mounted within a mounted with a  
20    mounting ring (350). The tubes are mounted such that there is a gap (355) between adjacent tubes. Optionally, a plurality of alumina or ceramic balls between 20 to 100mm in diameter rest on top of the impediment to form a bed and provide for diffusion and to promote the transfer of plasma heat to the ash to initially melt the ash into slag in the inter-zonal region.

25    Hot air is feed into the carbon conversion zone through perforations in the upper surface of the substantially parallel refractory line tubes (345).

30    Example 3

The general structure and design of the multi-zone carbon converter is as described above, in that the carbon conversion zone and slag zone are substantially the same as that described in Example 1. Referring to **Figure 27**, in the illustrated embodiment the multi-zone carbon converter (210) comprises a refractory-lined vertically-oriented  
35    chamber (315) having a processed feedstock input (**not shown**), syngas outlet (**not**



shown), a slag outlet (230), and zone-specific heating system (*i.e.* a system that can establish two temperature zones) comprising an air inlets (not shown) and plasma torch (240).

- 5 Referring to Figure 27, the inter-zonal region comprises a physical impediment to regulate the flow of material from the carbon conversion zone to the slag zone. In the instant embodiment, the physical impediment comprises a series of interconnected refractory bricks (245). The bricks are mounted on a mounting element (250) such that there are gaps (255) between adjacent bricks.

10

#### Example 4

- Referring to Figures 28, in the illustrated embodiment the multi-zone carbon converter (partially shown) comprises a refractory-lined vertically-oriented chamber (415) having a processed feedstock input (not shown), syngas outlet (not shown), a slag outlet (430), and zone-specific heating system (*i.e.* a system that can establish two temperature zones) comprising an air inlets (435) and plasma torch (440) and optional tapping spout (446).

- 20 Referring to Figure 28, the carbon conversion zone is central located and the slag zone is located towards the periphery of the chamber. The floor of the chamber is sloped such that the carbon conversion zone is upstream of the slag zone thereby promoting uni-directional movement of material between these zones. The two zones are separated by the inter-zonal region. The inter-zonal region comprises a physical impediment to regulate the flow of material from the carbon conversion zone to the slag zone. In the instant embodiment, the physical impediment comprises a series of substantially vertically-oriented, substantially parallel refractory-lined perforated pipes (445). Heated air is introduced into the carbon conversion zone through the perforations in the pipes to the center of the pile of processed feedstock thereby converting and heating the carbon in the processed feedstock. The air is heated slightly as it comes from the bottom, while cooling the pipes. Through air inlets (441) in the slag zone air is injected outside the row of pipes and serves to keep the outer surface of the pipes very hot so as to keep the slag from freezing.

The sloped bottom of the slag zone serves to drain the residue towards the side of the chamber where the plasma torch is located such that the residue is melted into molten slag. As the slag exits it drops through a water spray into a hopper below.

5    Example 5

The general structure and design of the multi-zone carbon converter is as described above, in that the carbon conversion zone and slag zone are substantially the same as that described in Example 1. Referring to **Figure 29** which illustrates part of the carbon conversion zone, the inter-zonal region and the slag zone, the multi-zone carbon converter (510) comprises a refractory-lined vertically-oriented chamber (515) having a processed feedstock input (**not shown**), syngas outlet (**not shown**), a slag outlet (530), and zone-specific heating system (*i.e.* a system that can establish two temperature zones) comprising an air inlets (**not shown**) and plasma torch (540).

15    Referring to **Figure 29**, the inter-zonal region comprises a physical impediment to regulate the flow of material from the carbon conversion zone to the slag zone. In the instant embodiment, the physical impediment comprises a cogwheel-shaped dome (545).

20    Example 6

The structure and design of the multi-zone carbon converter is as described above, in that the carbon conversion zone and slag zone are substantially the same as that described in Example 1, except for the design of the slag zone. Referring to **Figure 30** (which illustrates part of the carbon conversion zone, the inter-zonal region and the slag zone), the chamber at the slag zone includes a branch or hot gas generator (622) having a plasma torch (640), carbon and/or bag ash inputs (642) and hot air inlets (641).

30    Example 7

Referring to **Figure 6**, the general structure and design of the multi-zone carbon converter is as described above, in that the carbon conversion zone and slag zone are

substantially the same as that described in Example 1. Referring to Figure 6 which illustrates part of the carbon conversion zone, the inter-zonal region and the slag zone, the multi-zone carbon converter (610) comprises a refractory-lined vertically-oriented chamber (615) having a processed feedstock input (not shown), syngas outlet (not shown), a slag outlet (630), and zone-specific heating system (i.e. a system that can establish two temperature zones) comprising an air inlets (not shown) and plasma torch (640).

Referring to Figure 6, the inter-zonal region (which is contiguous with the slag zone) comprises a physical impediment to regulate the flow of material from the carbon conversion zone to the slag zone. In the instant embodiment, the physical impediment comprises a plurality of ceramic balls (645).

#### Example 8

Referring to Figure 32, the general structure and design of the multi-zone carbon converter is as described above, in that the carbon conversion zone and the inter-zonal region are substantially the same as that described in Example 1. The floor of the slag zone comprises a rotating slanted refractory table. The rotation of the table top facilitates the evacuation of the molten slag. Optionally, table can include a plurality of ceramic balls to facilitate plasma heat transfer. The floor of the slag zone can be elevated and retracted from the processing zones.

Referring to Figure 32 which illustrates part of the carbon conversion zone, the inter-zonal region and the slag zone, the multi-zone carbon converter (810) comprises a refractory-lined vertically-oriented chamber (815) having a processed feedstock input (not shown), syngas outlet (not shown), a slag outlet (830), and zone-specific heating system (i.e. a system that can establish two temperature zones) comprising an air inlets (not shown) and plasma torch (840) and impediment (845).

The refractory-line table top is mounted on a drive shaft (846) operatively connected to an externally mounted motor (847). The slag-floor assembly is readily detachable from the inter-zonal region and the carbon-converter zone and is mounted on an

elevating table on rails to facilitate clean out. A plurality of ceramic balls (848) promotes the transfer of plasma heat.

Optionally, molten slag is cooled by a water spray upon exiting the slag outlet (830) and the solidified slag falls onto a drag chain for removal.

#### Example 9

Figure 33 illustrates part of the carbon conversion zone, the inter-zonal region and the slag zone, the multi-zone carbon converter (910) comprises a refractory-lined vertically-oriented chamber (915) having a processed feedstock input (not shown), syngas outlet (not shown), a slag outlet (930), and zone-specific heating system (*i.e.* a system that can establish two temperature zones) comprising an air inlets (not shown), plasma torch (940), propane or natural gas burner (937) and impediment (945).

The impediment comprises a rotating refractory cone (921) mounted on a drive pedestal having a drive shaft (933) linked to an external motor (942). The lower portion of the rotating refractory comprises a well (978) in which slag accumulates prior to exiting the chamber. The impediment / slag-floor assembly is readily detachable from the inter-zonal region and the carbon-converter zone and is mounted on an elevating table on rails to facilitate clean out.

Optionally, molten slag is cooled by a water spray upon exiting the slag outlet (930) and the solidified slag falls onto a drag chain for removal.

#### Example 10

Referring to Figure 12, in the illustrated embodiment the multi-zone carbon converter (1010) comprises a refractory-lined vertically-oriented chamber (1015) having a processed feedstock input (1020), syngas outlet (1025) in communication with a plasma gas refining chamber (1066), a slag outlet (1030), an agitator (1031) with externally mounted motor assembly (1032), and zone-specific heating system (*i.e.* a

system that can establish two temperature zones) comprising air inlets (1041) and plasma torch (1040).

5 The inter-zonal region comprises a physical impediment to regulate the flow of material from the carbon conversion zone to the slag zone. In the instant embodiment, the physical impediment comprises a rotating grate (1045) mounted within the inter-zonal region. Residual solid material transits the inter-zonal region and melts within the slag zone. Figures 12A and B illustrate exemplary grate designs.

10

**THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE  
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:**

1. A multi-zone carbon converter for converting processed feedstock to syngas and  
5 slag comprising  
a chamber comprising a carbon conversion zone in communication with a slag  
zone, wherein the carbon conversion zone and the slag zone are separated by an inter-  
zonal region;  
the carbon conversion zone comprising a processed feedstock input for  
10 receiving processed feedstock from a source, a syngas outlet and an air input;  
the inter-zonal region comprising an impediment to limits the flow of material  
between the carbon conversion zone and the slag zone by either partial or  
intermittently occluding the inter-zonal region;  
the slag zone comprising a plasma heat source and a slag outlet;  
15 wherein the processed feedstock is converted to the syngas and ash in the carbon  
conversion zone, and the ash is converted into molten slag in the inter-zonal region  
and/or the slag zone through the application of heat from the plasma heat source.
2. The multi-zone carbon converter of claim 1, wherein the air input is heated air  
20 inlets.
3. The multi-zone carbon converter of claim 1, wherein the air input is one or more  
air boxes.
- 25 4. The multi-zone carbon converter of claim 1, 2 or 3, wherein the impediment is a  
solid pre-cast refractory dome mounted in the inter-zonal region via four wedge-  
shaped refractory bricks and is sized to provide a gap or space between the internal  
wall of the multi-zone carbon converter and the dome.
- 30 5. The multi-zone carbon converter of claim 4, wherein the chamber is substantially  
vertically-oriented, cylindrical chamber and the inter-zonal forms a constriction of the  
chamber.

6. The multi-zone carbon converter of claim 5, wherein the slag zone tapers towards a conical slag outlet.
7. The multi-zone carbon converter of claim 1, 2 or 3, wherein the impediment is a  
5 grate.
8. The multi-zone carbon converter of any one of claims 1 to 7, wherein the inter-zonal region further comprises heat transfer elements for transferring plasma heat from the slag zone to the inter-zonal region.
- 10
9. The multi-zone carbon converter of any one of claims 1 to 8, further comprising a control system.
10. The multi-zone carbon converter of any one of claims 1 to 9, further comprising a  
15 processed feedstock pre-treatment module.
11. The multi-zone carbon converter of any one of claims 1 to 10, further comprising a slag cooling module.
- 20 12. The multi-zone carbon converter of any one of claims 1 to 11, wherein the plasma heat source is a plasma torch.

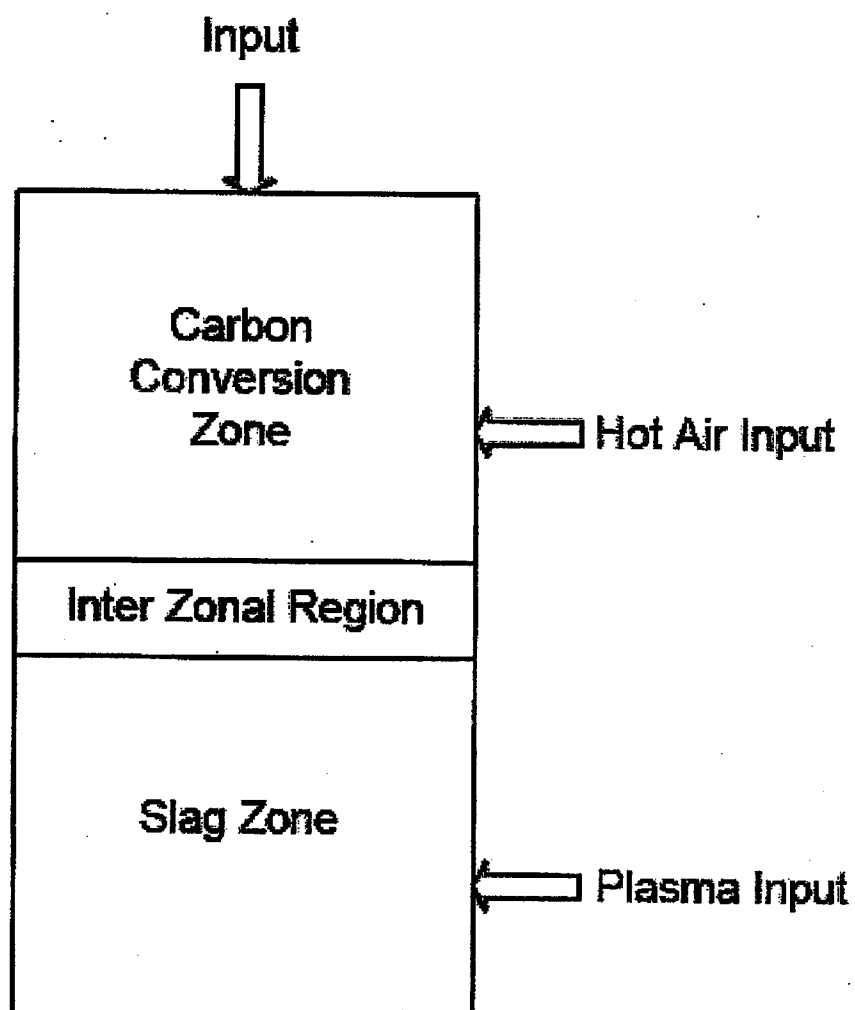


FIGURE 1



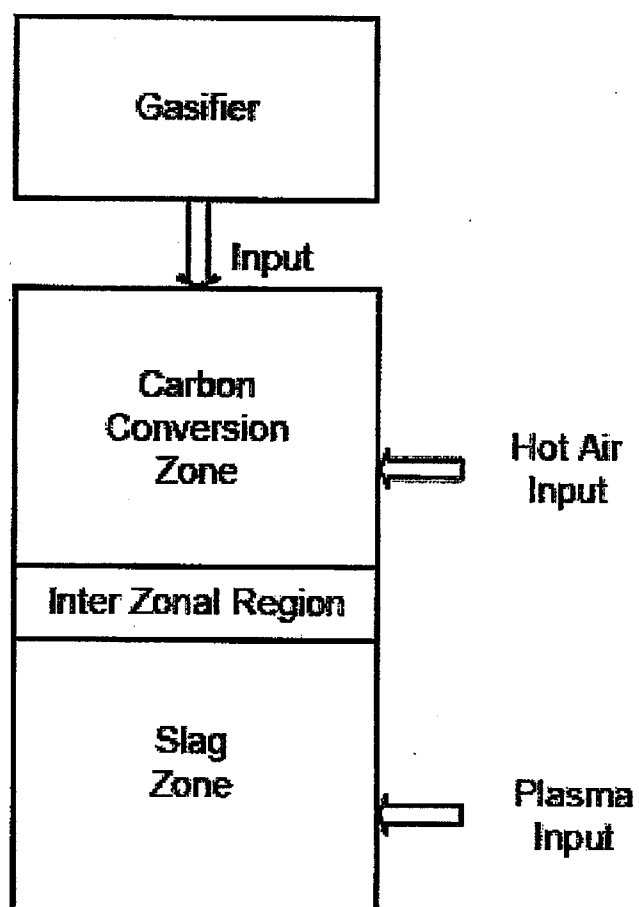


FIGURE 2

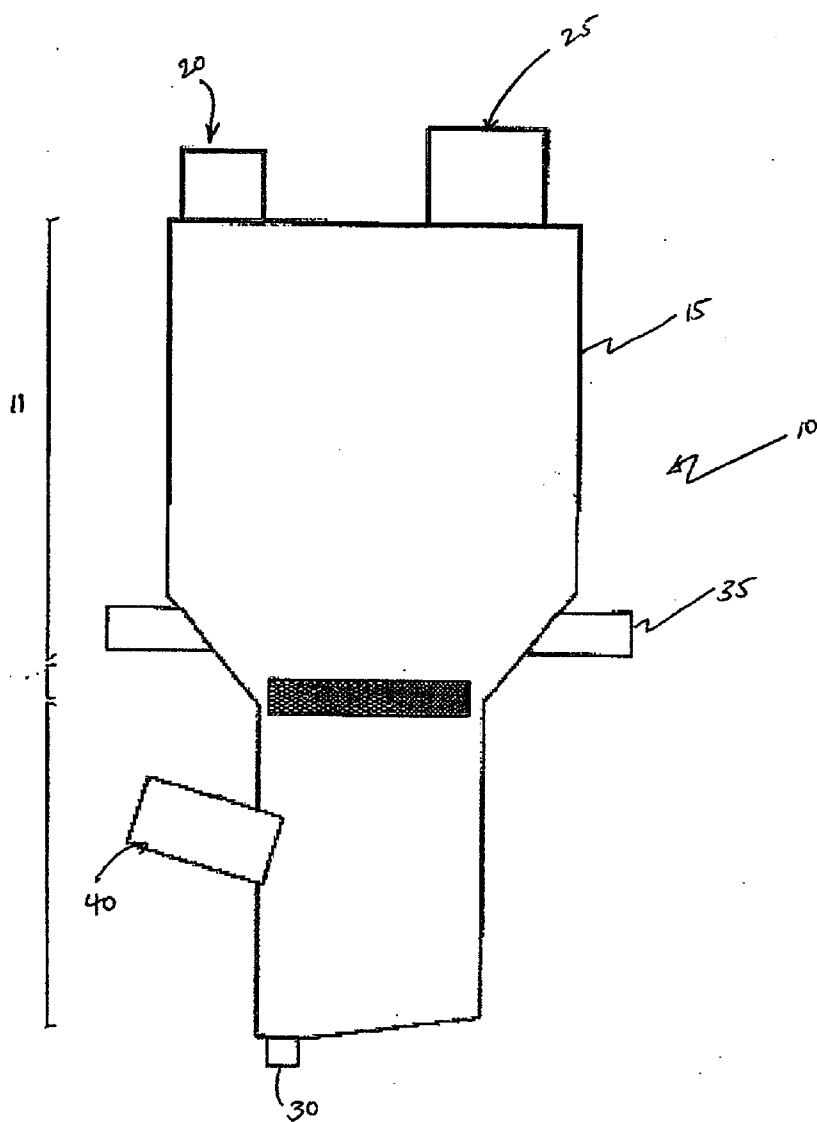


FIGURE 3

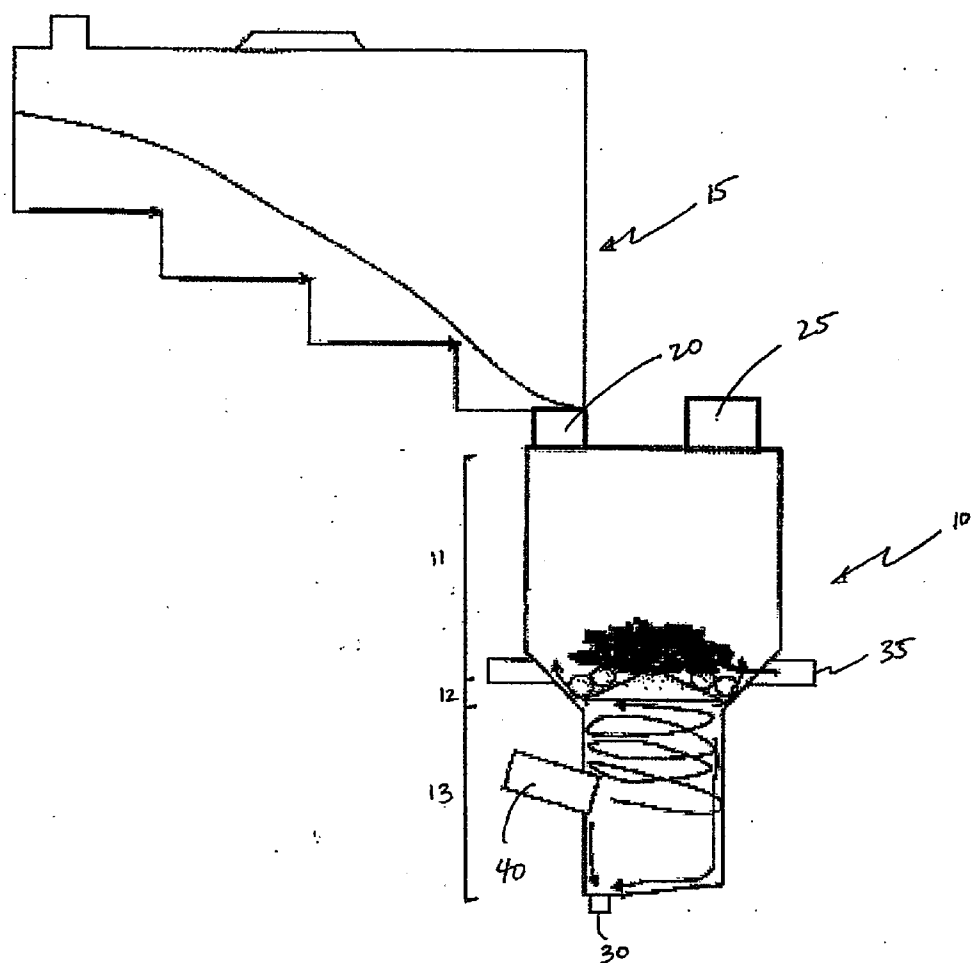


FIGURE 4

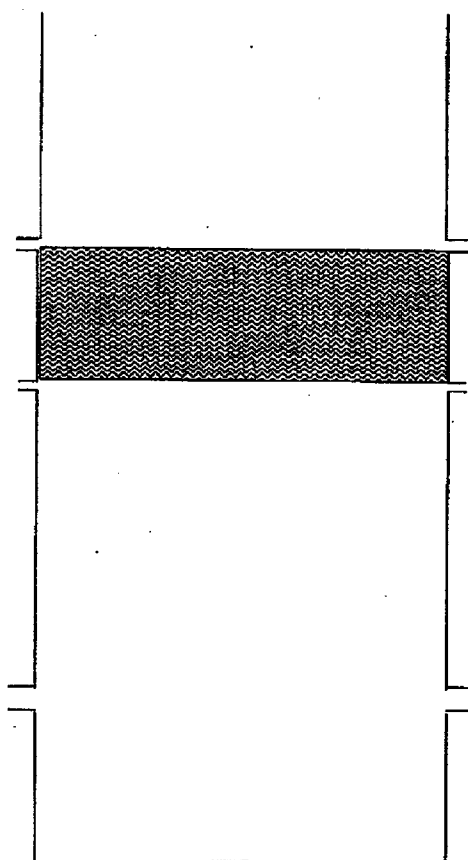


FIGURE 5

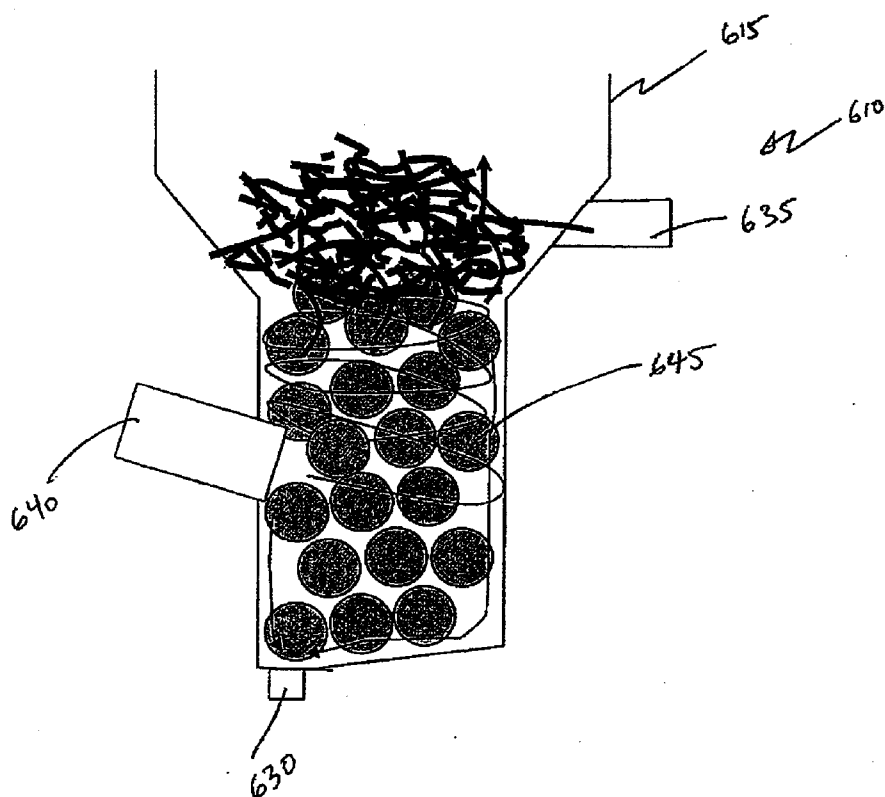


FIGURE 6

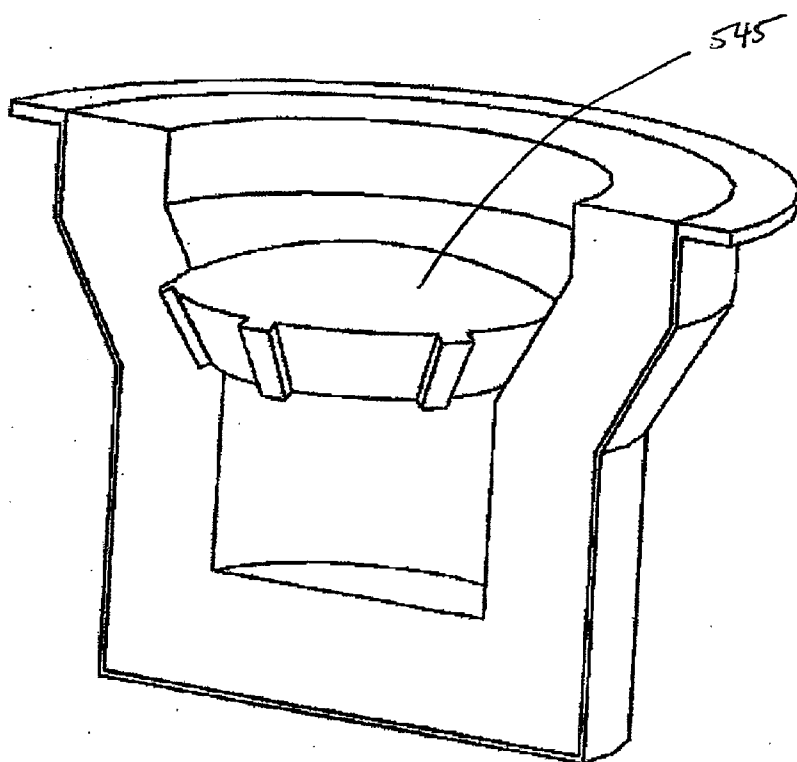


FIGURE 7

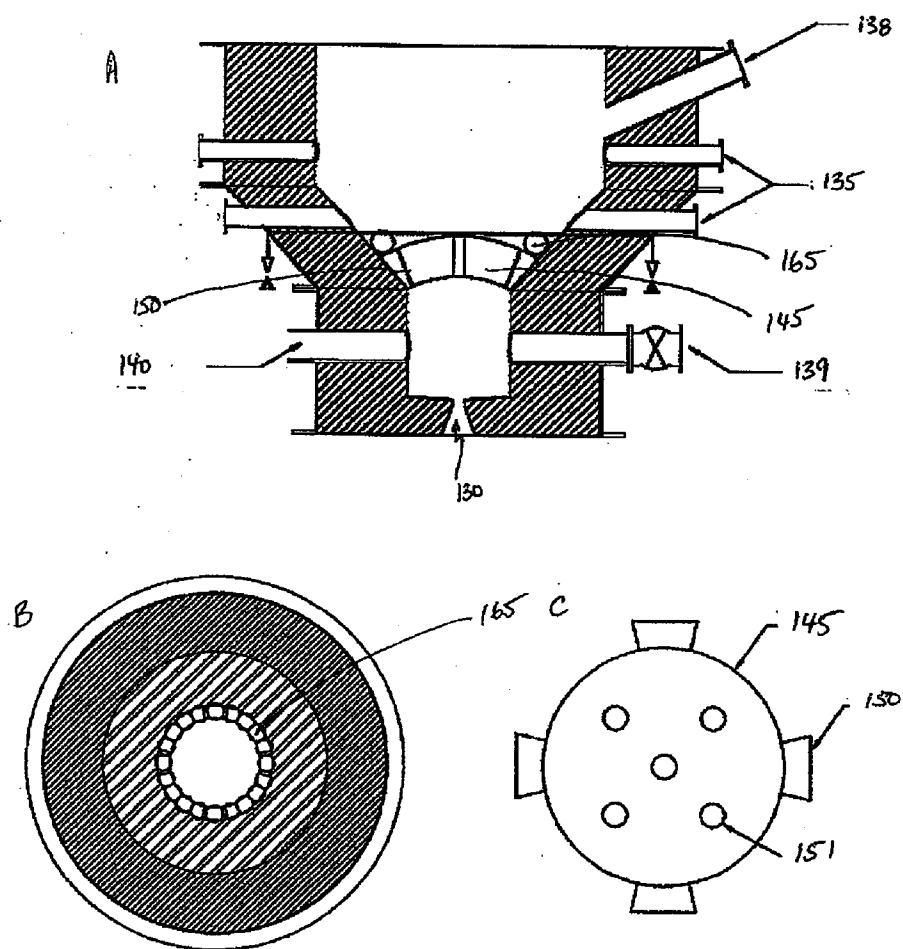


FIGURE 8

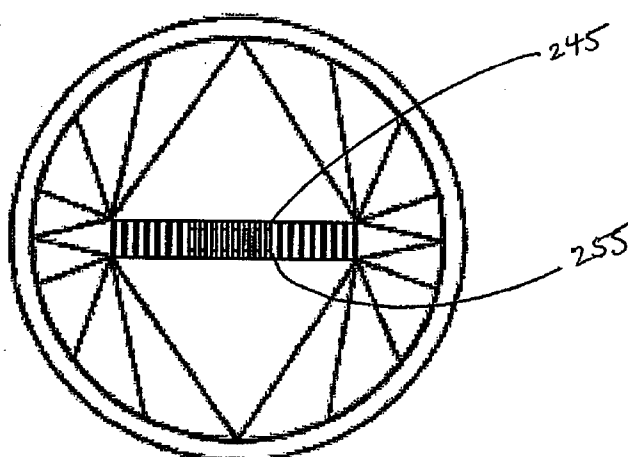


FIGURE 9



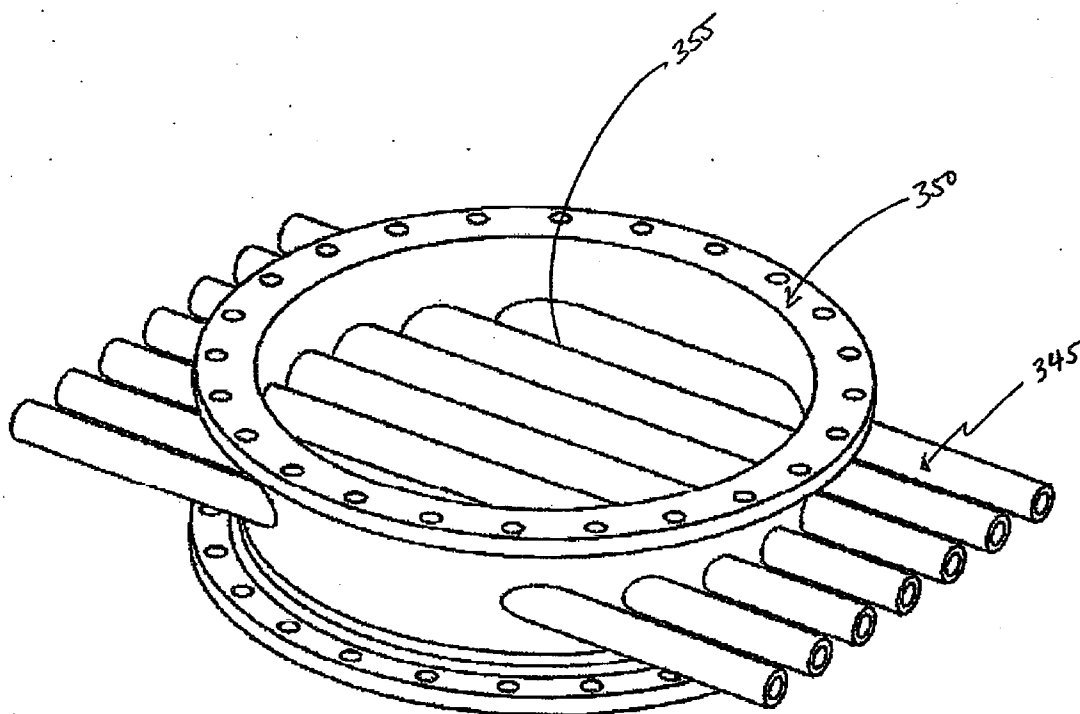


FIGURE 10

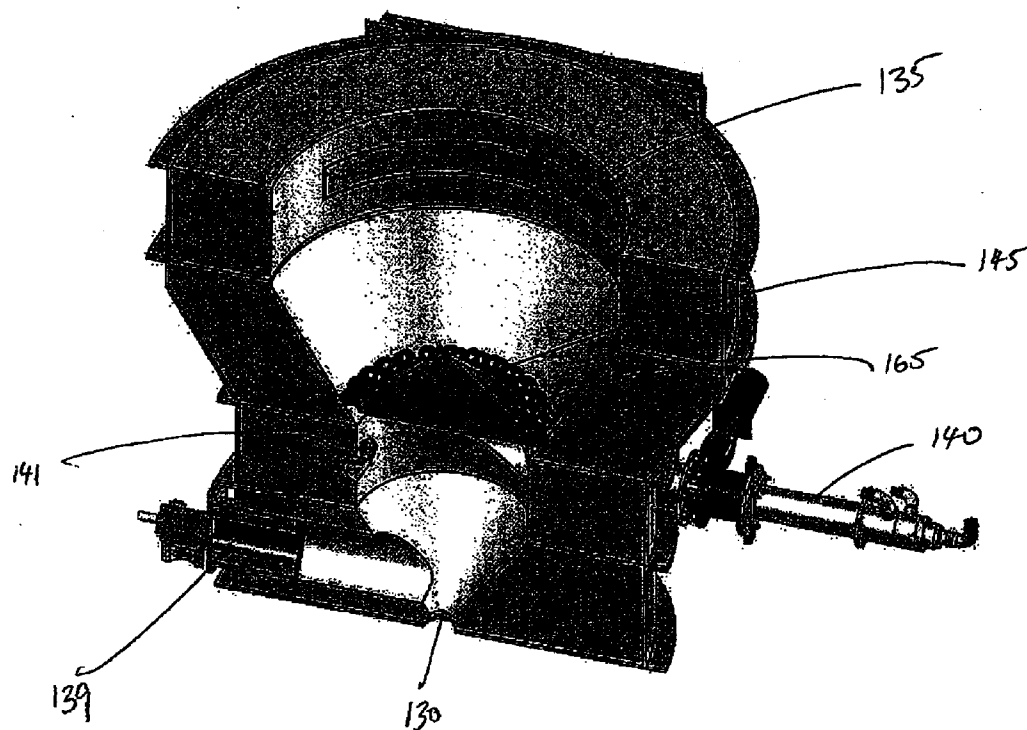


FIGURE 11



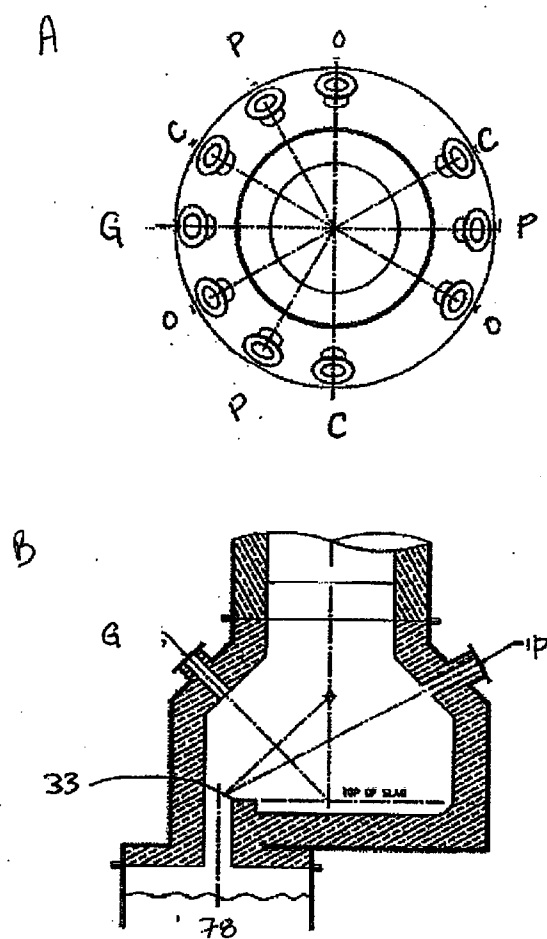


FIGURE 13

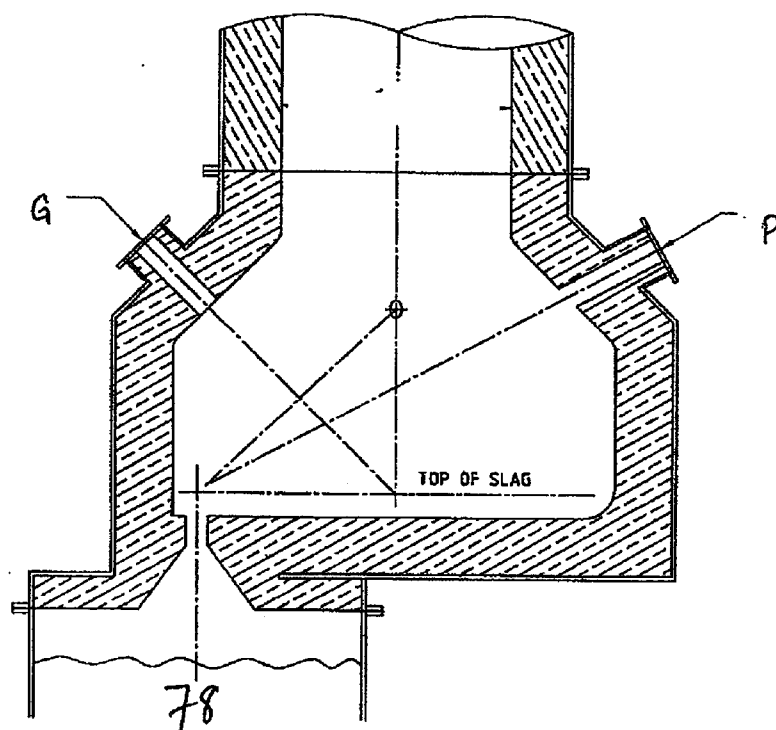


FIGURE 14

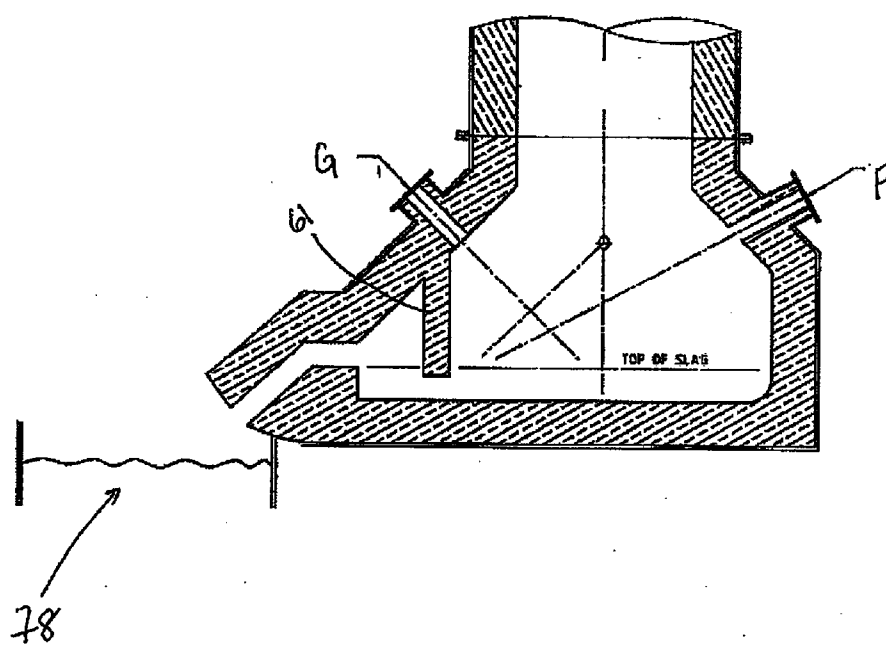


FIGURE 15

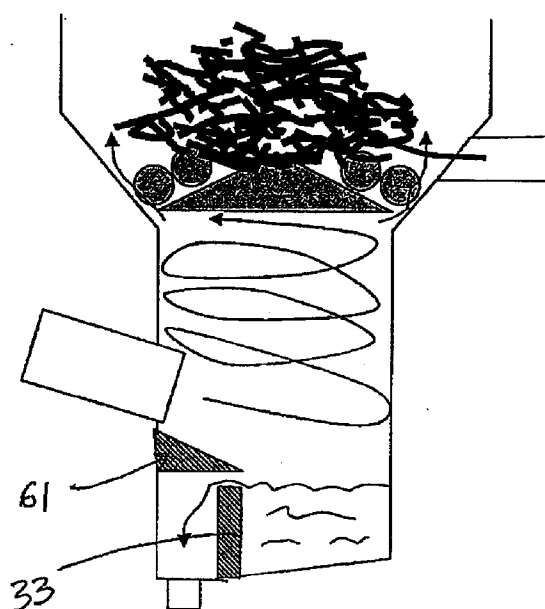


FIGURE 16

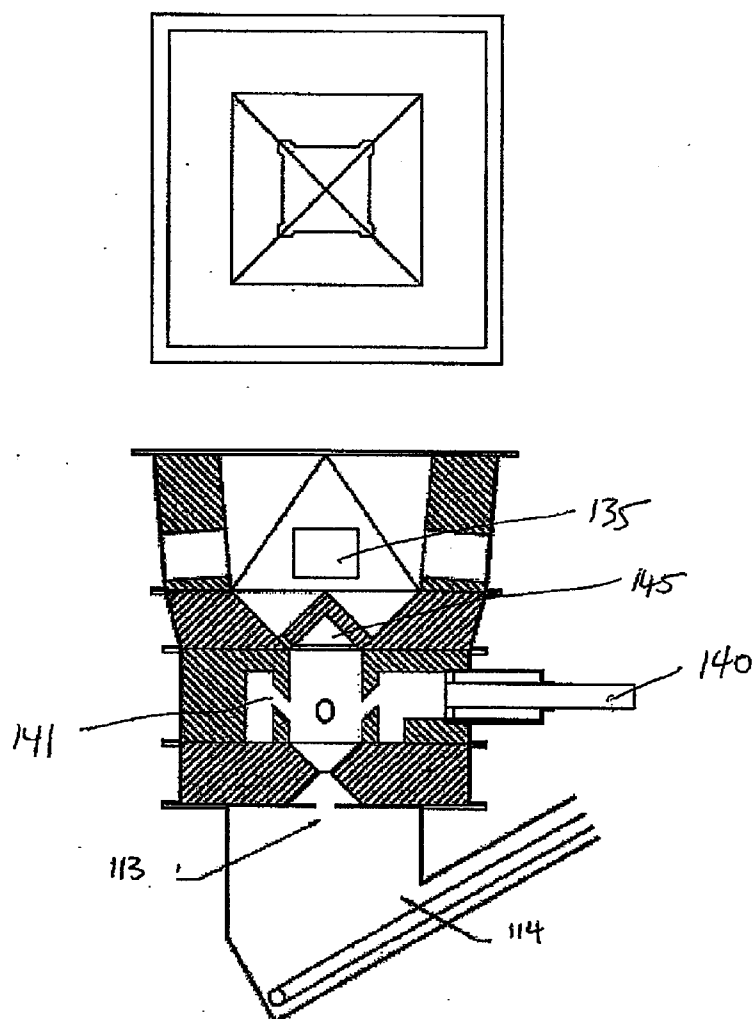


FIGURE 17



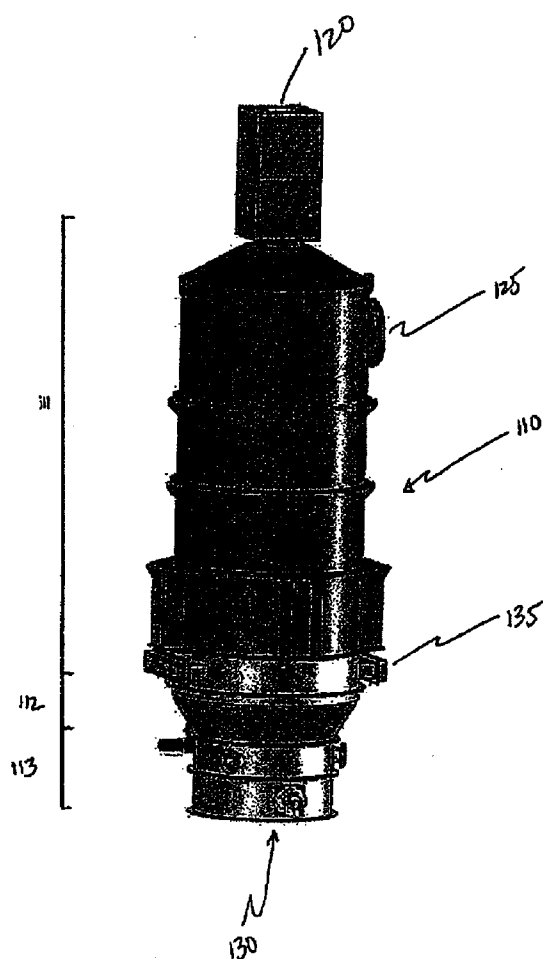


FIGURE 18

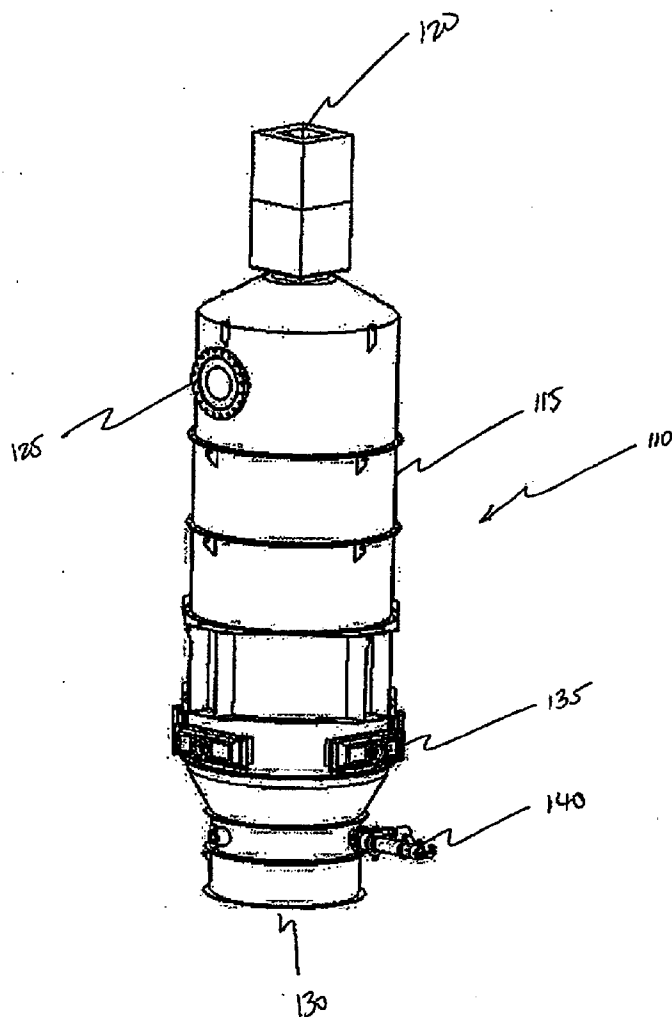


FIGURE 19

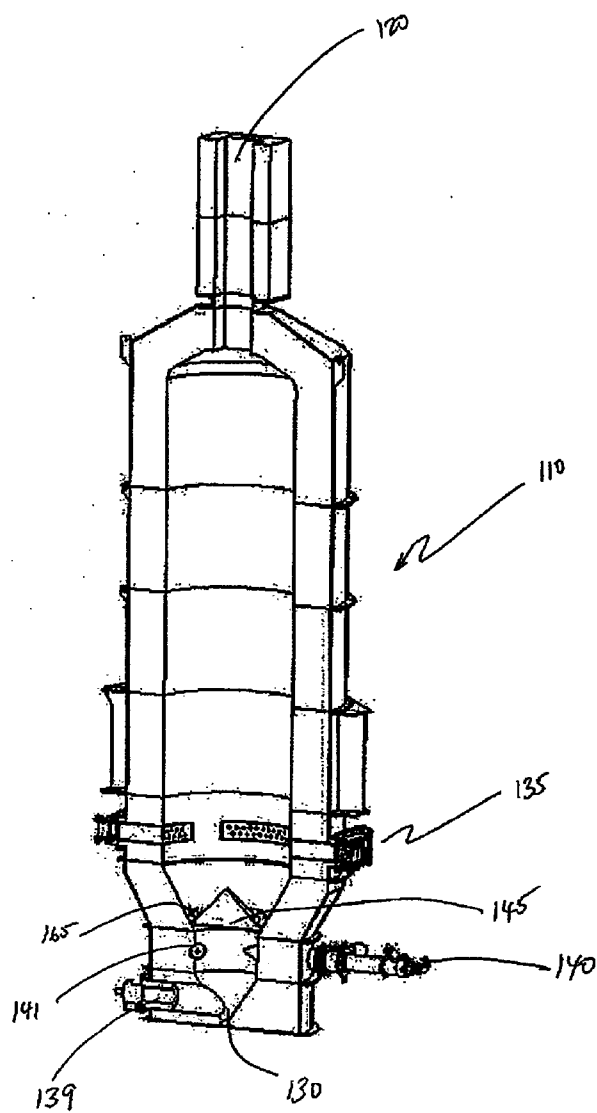


FIGURE 20

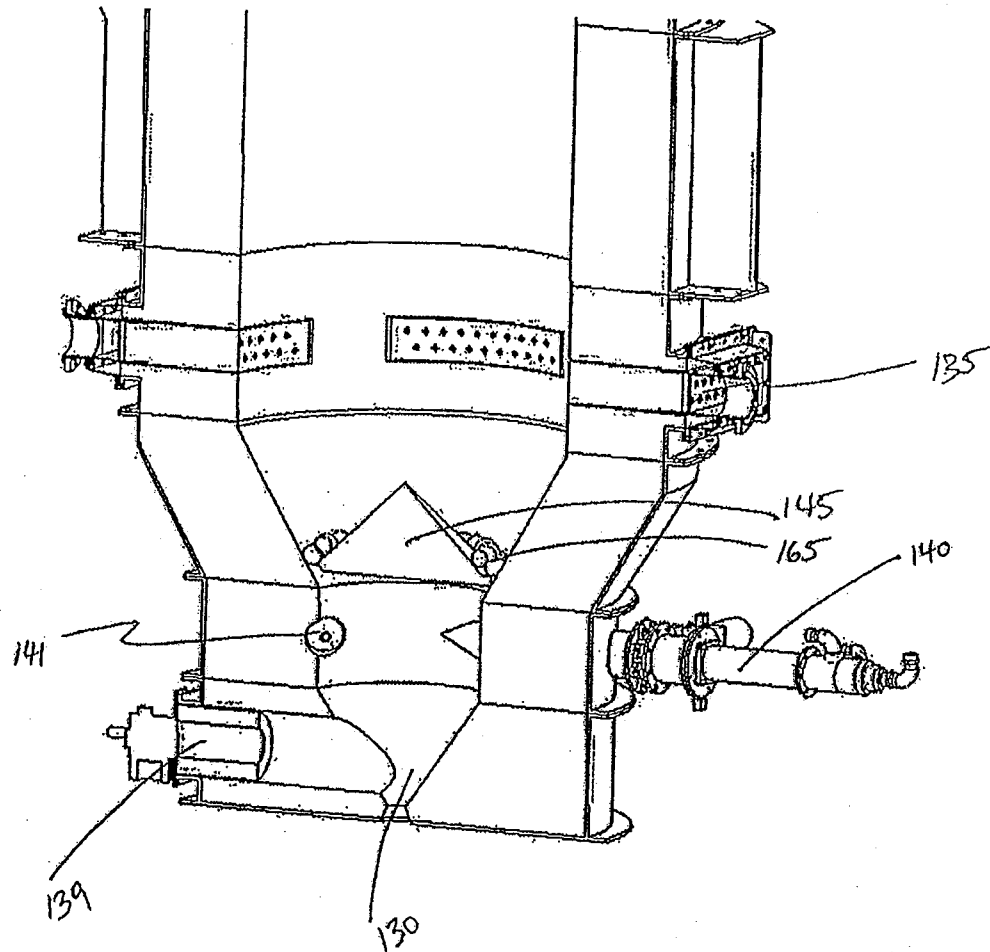


FIGURE 21

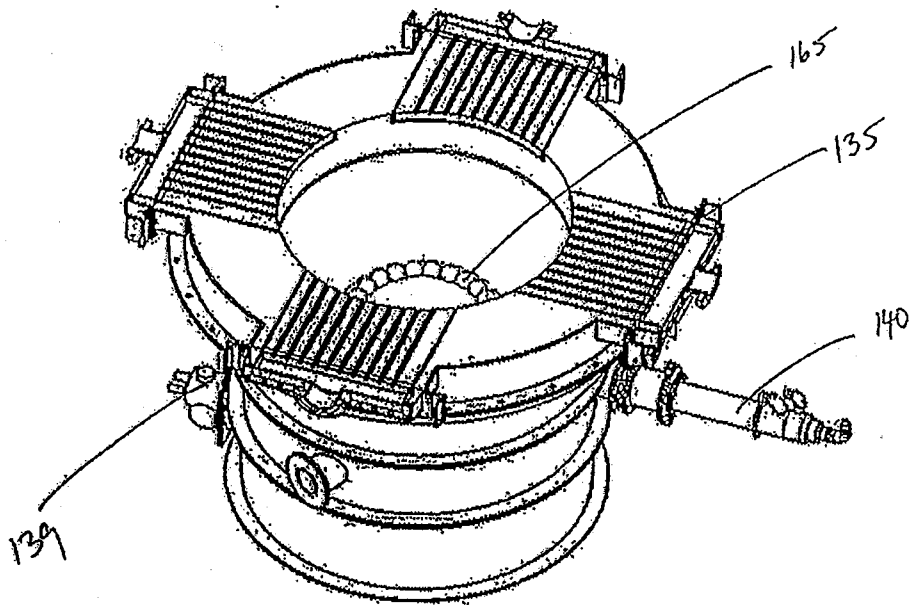


FIGURE 22

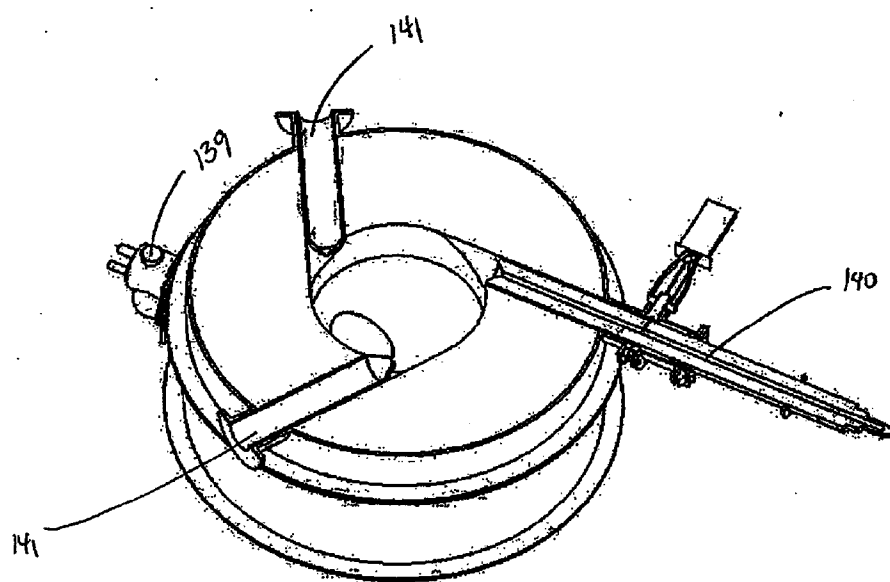


FIGURE 23

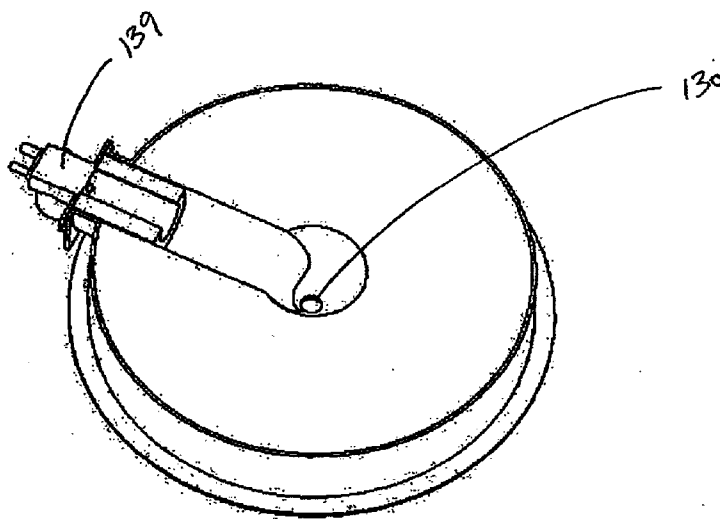


FIGURE 24

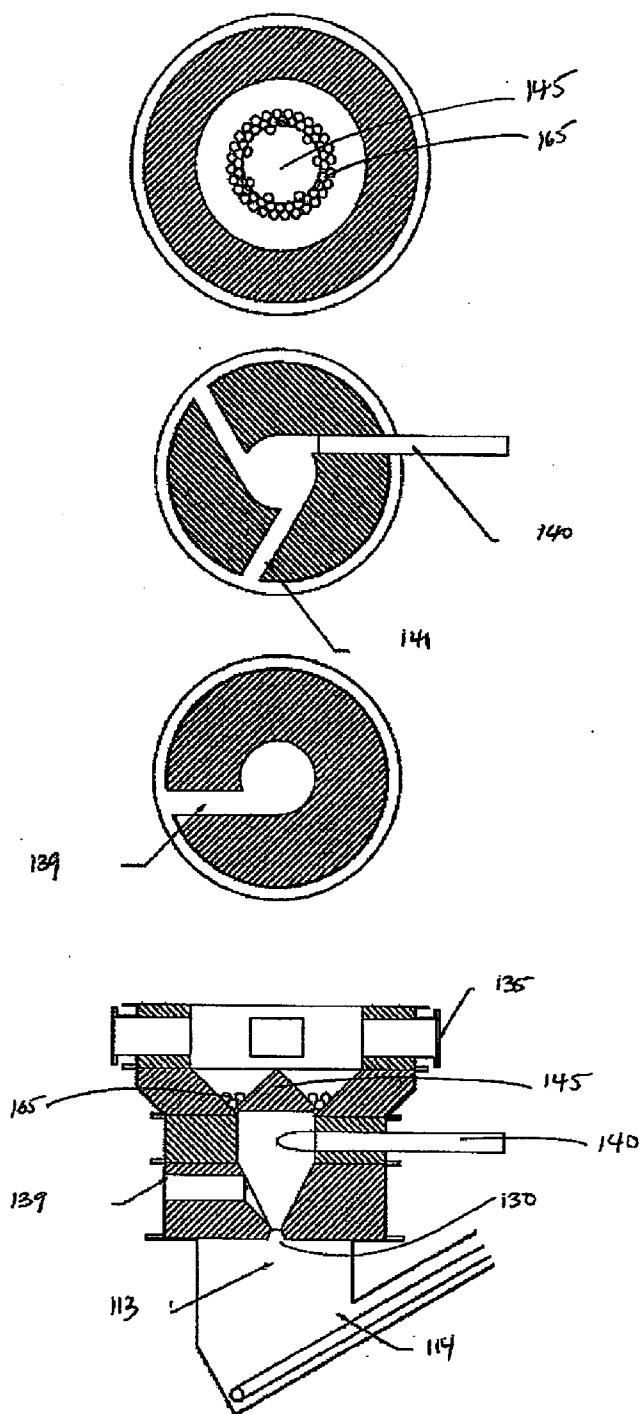


Figure 25



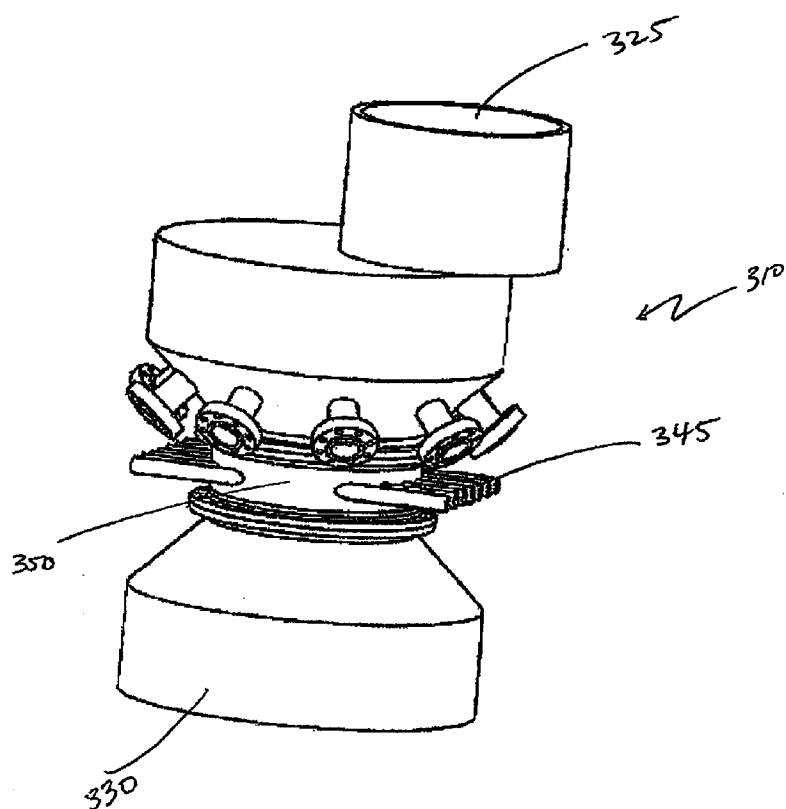


FIGURE 26

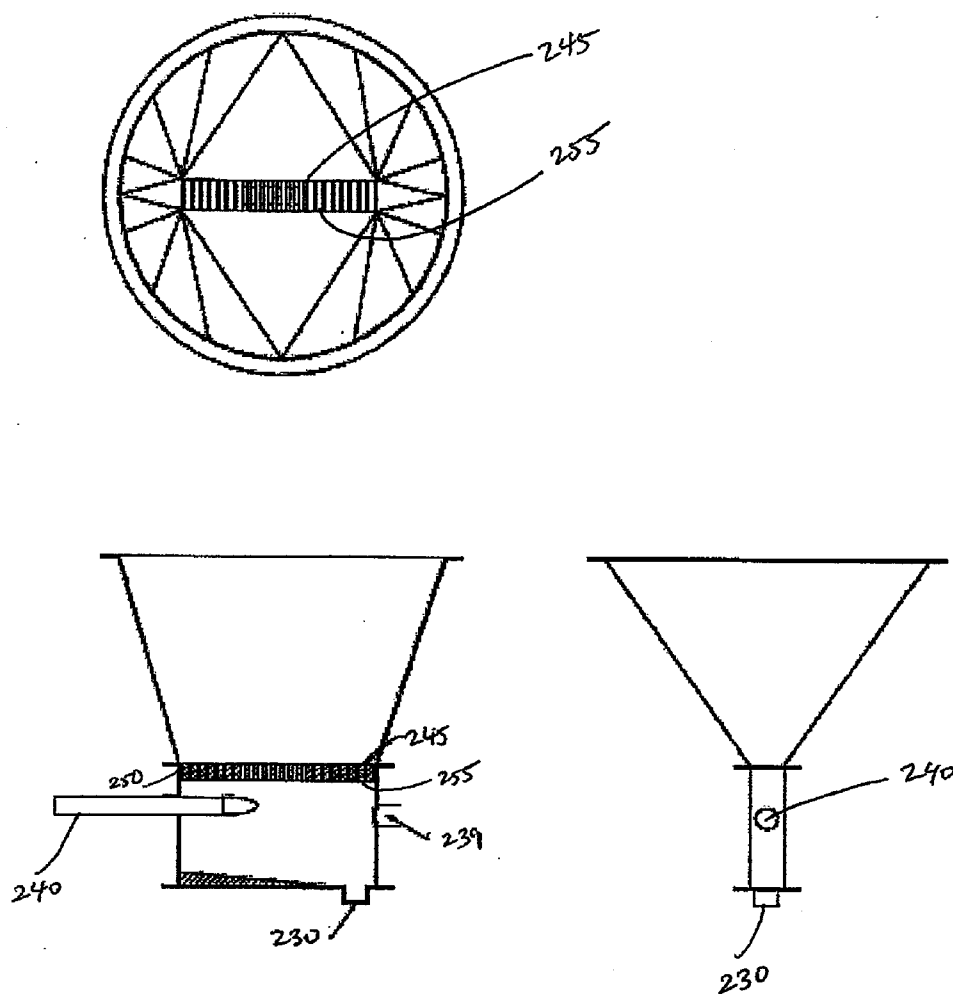


FIGURE 27

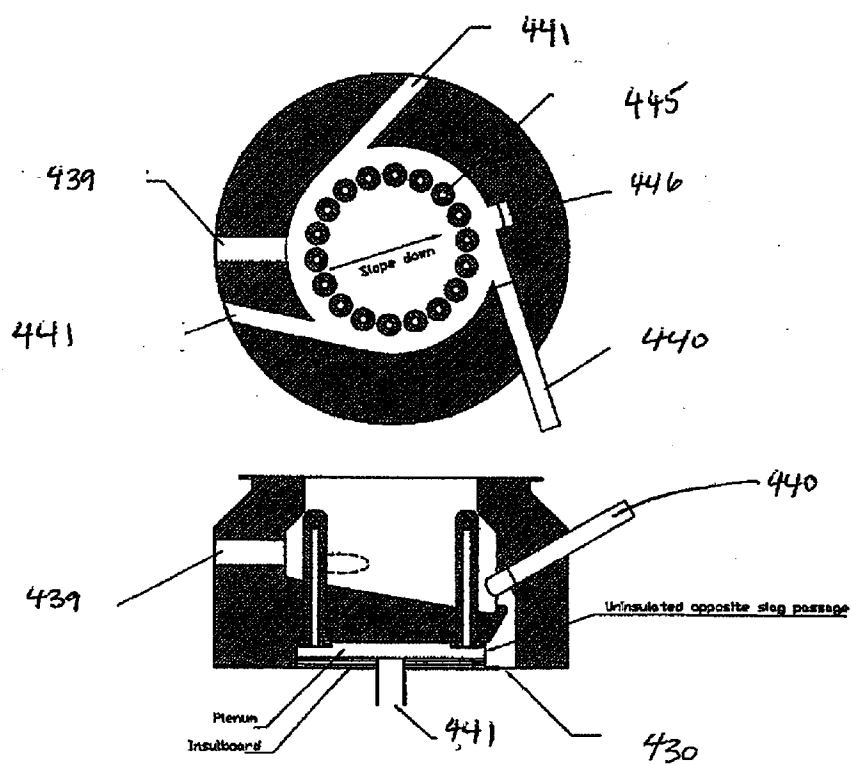


FIGURE 28

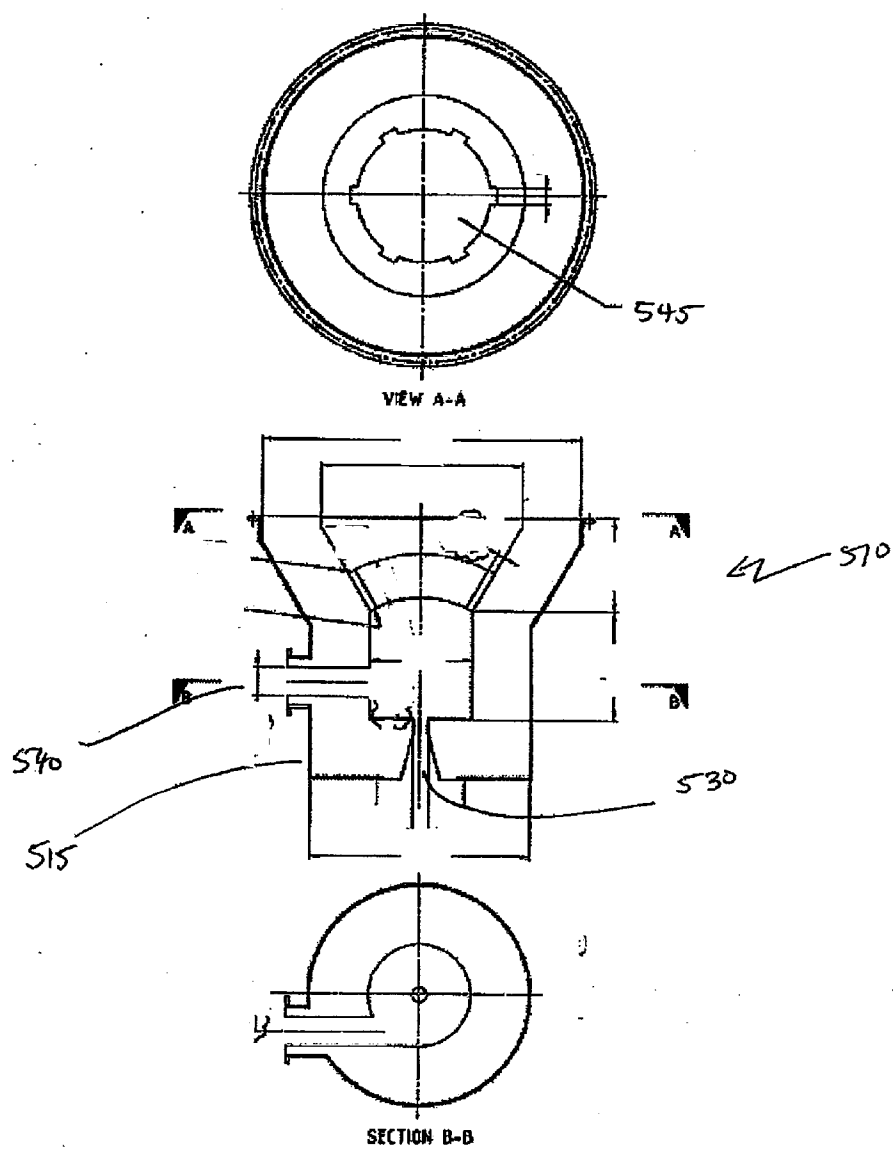


FIGURE 29

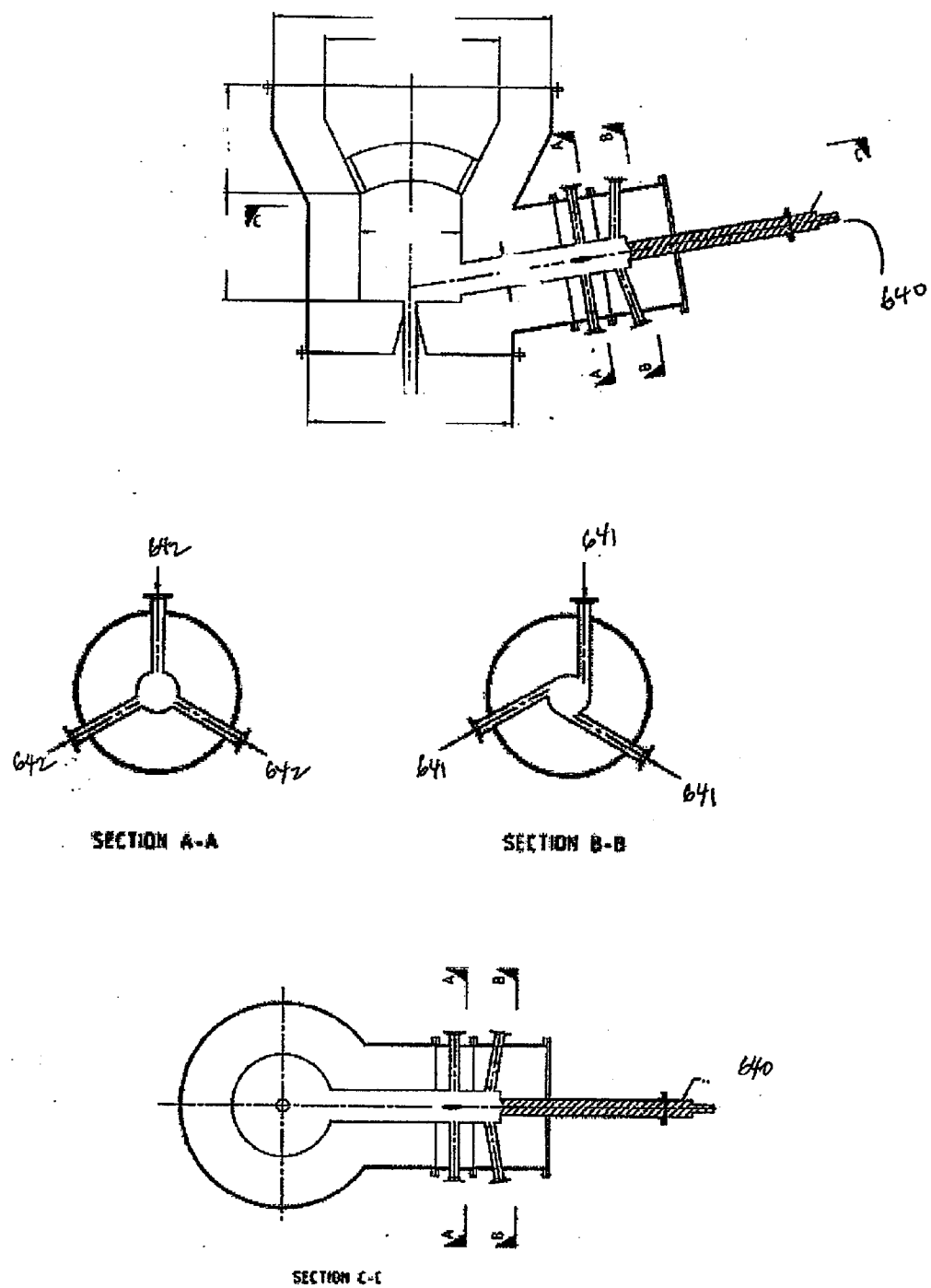


FIGURE 30

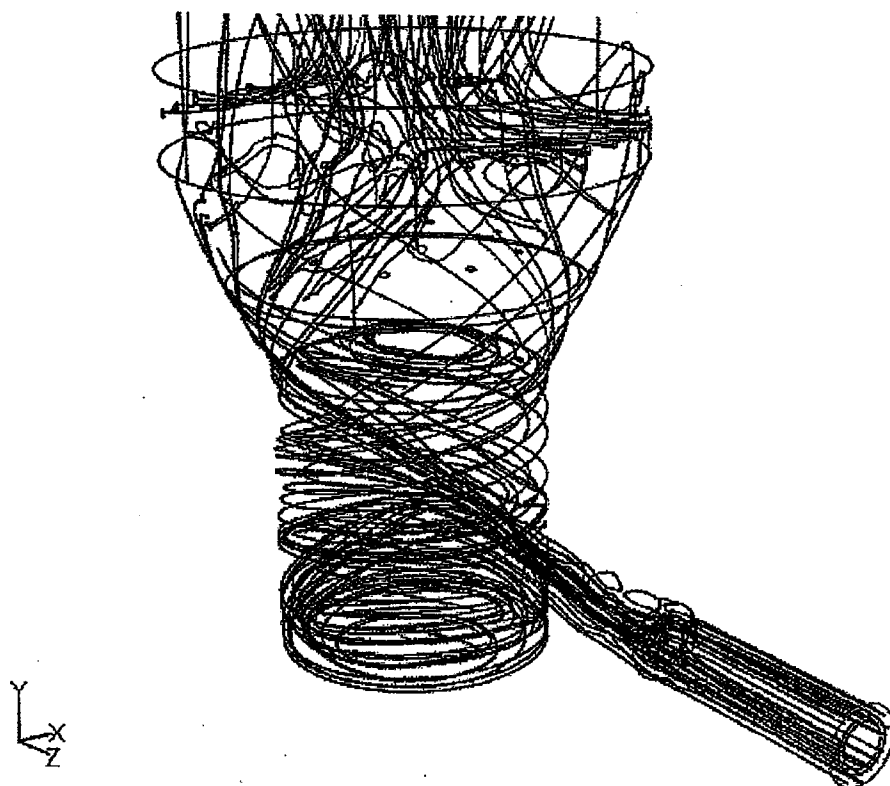


Figure 31A

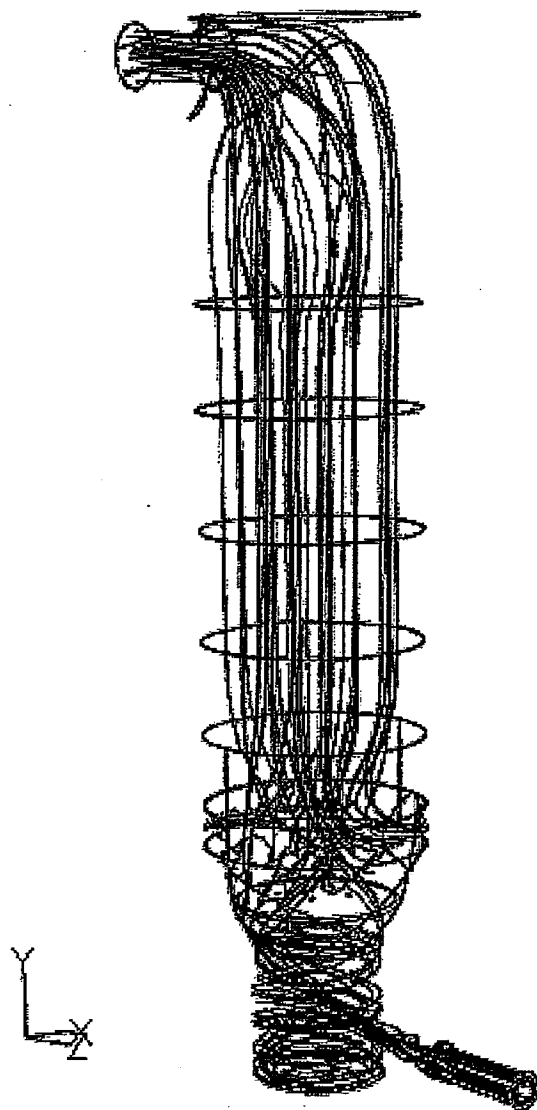


FIGURE 31B

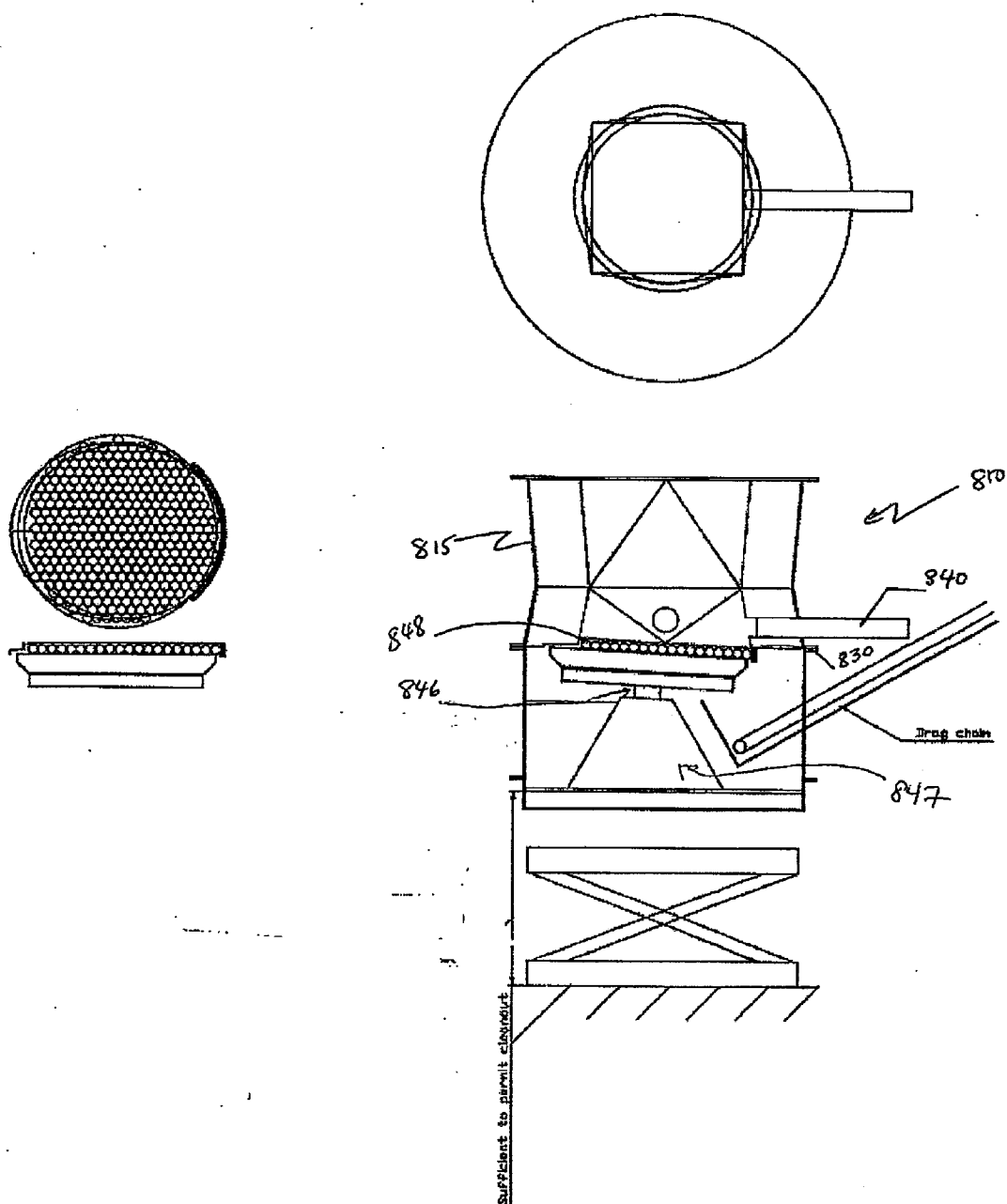


FIGURE 32



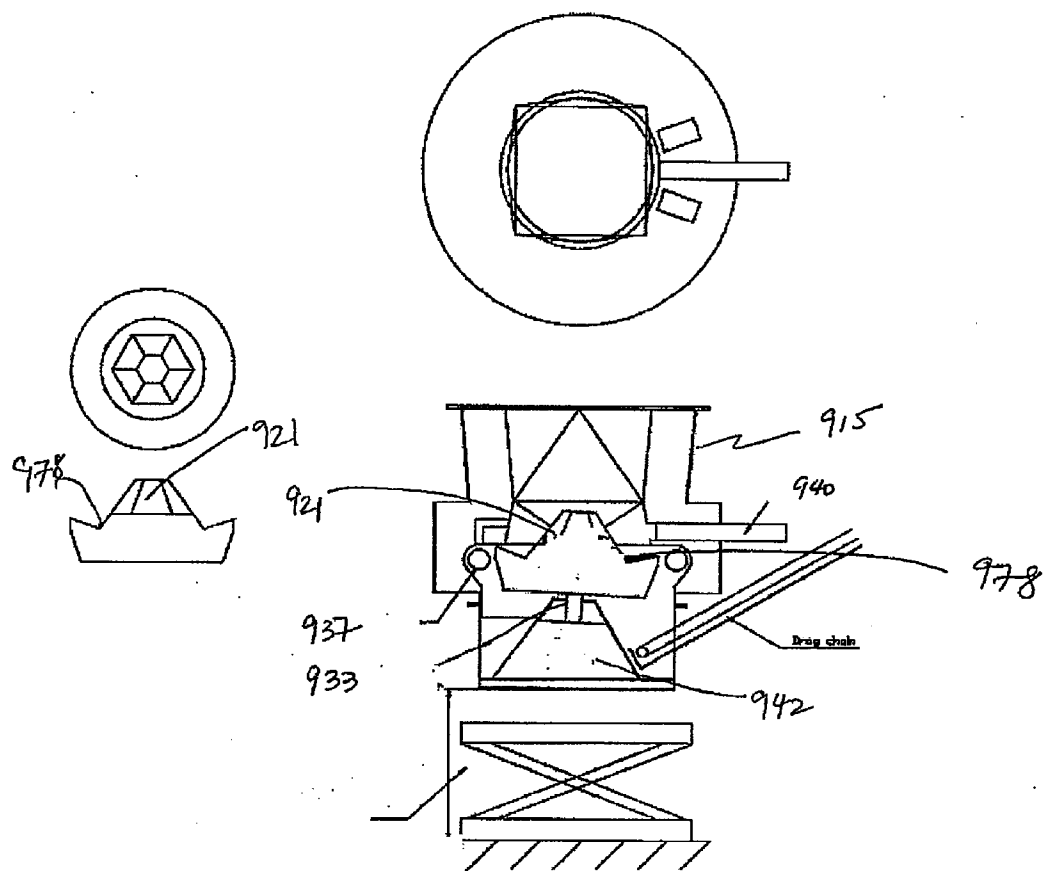


FIGURE 33

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/CA2008/000452

## A. CLASSIFICATION OF SUBJECT MATTER

IPC: **F23G 5/38** (2006.01) , **A62D 3/40** (2007.01) , **C01B 3/02** (2006.01) , **C01B 31/18** (2006.01) , **C02F 1/02** (2006.01) , **C02F 11/10** (2006.01) , **F23G 5/027** (2006.01) , **B09B 3/00** (2006.01) , **C10J 3/00** (2006.01)  
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: F23G 5/24, F23G 5/26, F23G 5/28, A62D 3/40, C01B 3/02, C01B 31/18, C02F 1/02, C02F 11/10, F23G 5/027, B09B 3/00, C10J 3/00  
USPC: 110/250, 110/346, 219/121.36, 219/121.37, 373/018, 588/311

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
none

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

Canadian Patents Database, Delphion

keywords: plasma, gasifier, slag, zone, syngas, neck, dome, brick, wedge, carbon, converter, refractory, heat, exchange, ball, sphere, baffle

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO2006/128286A1 (PLASCO ENERGY GROUP INC.) 7 December 2006 (07-12-2006) *fig. 22*	1-3, 7-12
A	US4063521A (ECONO-THERM ENERGY SYSTEMS CORPORATION) 20 December 1977 (20-12-1977)	1-12
A	US4941415A (ENTECH CORPORATION) 17 July 1990 (17-07-1990)	1-12

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

☒ See patent family annex.

* Special categories of cited documents :	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search

30 June 2008 (30-06-2008)

Date of mailing of the international search report

3 July 2008 (03-07-2008)

Name and mailing address of the ISA/CA  
Canadian Intellectual Property Office  
Place du Portage I, C114 - 1st Floor, Box PCT  
50 Victoria Street  
Gatineau, Quebec K1A 0C9  
Facsimile No.: 001-819-953-2476

Authorized officer

Andrew Davidson 819- 953-4505

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.  
**PCT/CA2008/000452**

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
WO 2006128286A1	07-12-2006	AU 2006254672A1	07-12-2006
		AU 2006254673A1	07-12-2006
		AU 2006254673A8	07-12-2006
		CA 2610806A1	07-12-2006
		CA 2610808A1	07-12-2006
		EP 1888717A1	20-02-2008
		EP 1896553A1	12-03-2008
		KR 20080028409A	31-03-2008
		US 2007258869A1	08-11-2007
		US 2007266632A1	22-11-2007
		US 2007266633A1	22-11-2007
		US 2007266634A1	22-11-2007
		US 2007284453A1	13-12-2007
		US 2007289216A1	20-12-2007
		US 2008104887A1	08-05-2008
		US 2008147241A1	19-06-2008
		WO 2006128285A1	07-12-2006
		WO 2007131234A2	15-11-2007
		WO 2007131234A3	03-01-2008
		WO 2007131235A2	15-11-2007
		WO 2007131236A2	15-11-2007
		WO 2007131236A3	03-01-2008
		WO 2007131239A2	15-11-2007
		WO 2007131240A2	15-11-2007
		WO 2007131240A3	27-12-2007
		WO 2007131241A2	15-11-2007
		WO 2007131241A3	03-01-2008
		WO 2008011213A2	24-01-2008
		WO 2008011213A3	10-04-2008
US 4063521A	20-12-1977	None	
US 4941415A	17-07-1990	AT 100558T	15-02-1994
		CA 2028915A1	03-05-1991
		CA 2028915C	11-04-1995
		DE 69006176D1	03-03-1994
		DE 69006176T2	18-08-1994
		DK 426471T3	30-05-1994
		EP 0426471A2	08-05-1991
		EP 0426471A3	09-10-1991
		EP 0426471B1	19-01-1994
		ES 2048444T3	16-03-1994
		JP 3194310A	26-08-1991

# **A MULTI-ZONE CARBON CONVERSION SYSTEM WITH PLASMA MELTING**

## **FIELD OF THE INVENTION**

5

This invention pertains to the field of carbonaceous feedstock gasification and in particular, to a multi-zone carbon converter.

## **BACKGROUND OF THE INVENTION**

10

Gasification is a process that enables the conversion of carbonaceous feedstock, such as municipal solid waste (MSW) or coal, into a combustible gas. The gas can be used to generate electricity, steam or as a basic raw material to produce chemicals and liquid fuels.

15

Possible uses for the gas include: the combustion in a boiler for the production of steam for internal processing and/or other external purposes, or for the generation of electricity through a steam turbine; the combustion directly in a gas turbine or a gas engine for the production of electricity; fuel cells; the production of methanol and  
20 other liquid fuels; as a further feedstock for the production of chemicals such as plastics and fertilizers; the extraction of both hydrogen and carbon monoxide as discrete industrial fuel gases; and other industrial applications.

25

Generally, the gasification process consists of feeding carbonaceous feedstock into a heated chamber (the gasifier) along with a controlled and/or limited amount of oxygen and optionally steam. In contrast to incineration or combustion, which operates with excess oxygen to produce  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{SO}_x$ , and  $\text{NO}_x$ , gasification processes produce a raw gas composition comprising  $\text{CO}$ ,  $\text{H}_2$ ,  $\text{H}_2\text{S}$ , and  $\text{NH}_3$ . After clean-up, the primary gasification products of interest are  $\text{H}_2$  and  $\text{CO}$ .

30

Useful feedstock can include any municipal waste, waste produced by industrial activity and biomedical waste, sewage, sludge, coal, heavy oils, petroleum coke, heavy refinery residuals, refinery wastes, hydrocarbon contaminated soils, biomass, and agricultural wastes, tires, and other hazardous waste. Depending on the origin of