US 20070289216A1

(19) United States

(12) Patent Application Publication

Tsangaris et al.

(10) Pub. No.: US 2007/0289216 A1

(43) Pub. Date: Dec. 20, 2007

(54) **GASIFIER COMPRISING VERTICALLY SUCCESSIVE PROCESSING REGIONS**

(75) Inventors: **Andreas Tsangaris**, Ottawa (CA); **Margaret Swain**, Ottawa (CA)

Correspondence Address:
MORRISON & FOERSTER LLP
12531 HIGH BLUFF DRIVE
SUITE 100
SAN DIEGO, CA 92130-2040 (US)

(73) Assignee: **Plasco Energy Group Inc.**, Kanata (CA)

(21) Appl. No.: **11/758,633**

(22) Filed: **Jun. 5, 2007**

(30) **Foreign Application Priority Data**

Jun. 5, 2006 (CA) PCT/CA06/00881

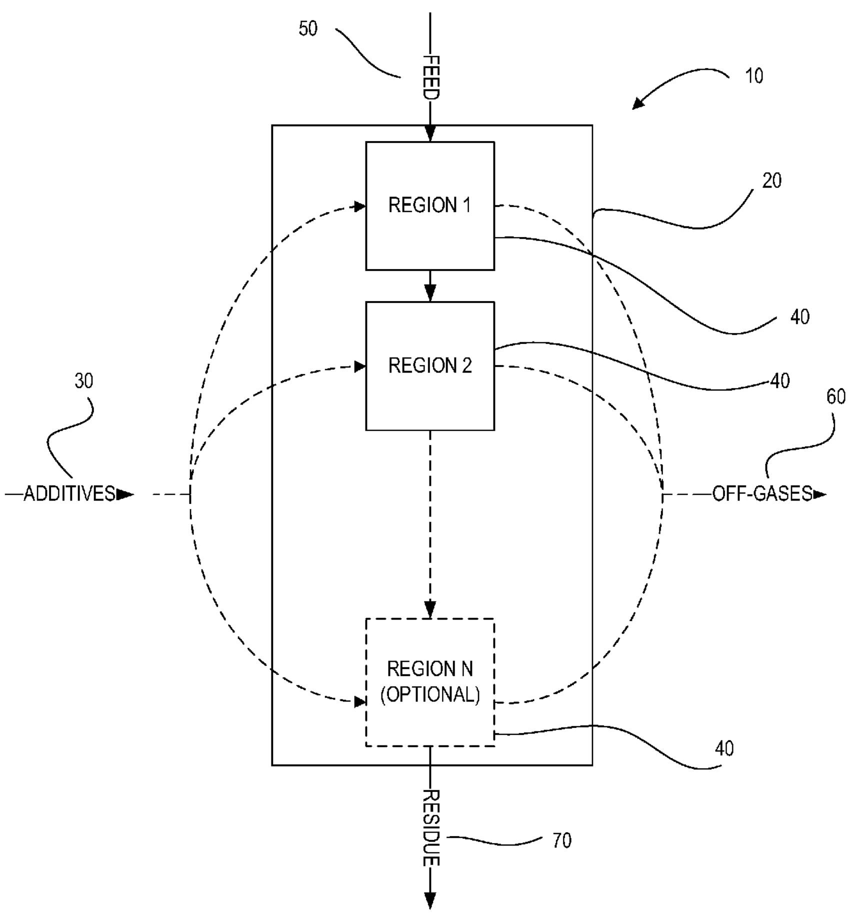
Publication Classification

(51) **Int. Cl.**
C10J 3/46 (2006.01)
C10J 3/48 (2006.01)

(52) **U.S. Cl.** .... **48/197 R**; 48/61; 48/62 R; 48/89

(57) **ABSTRACT**

The present invention provides a vertically oriented gasifier comprising vertically successive processing regions for conversion of carbonaceous feedstock into gas. The gasifier comprises of: one or more processing chambers with two or more vertically successive processing regions being distributed within said one or more processing chambers, within each one of which a respective process selected from the group consisting of drying, volatilization and carbon conversion is at least partially favoured, The processing regions are identified by temperature ranges respectively enabling each said respective process. One or more additive input elements are associated with the processing regions for inputting additives to promote each said at least partially favoured process therein. In addition, the gasifier comprises one or more material displacement control modules adapted to control a vertical movement of the feedstock through said processing regions to enhance each said at least partially favoured process, one or more feedstock inputs located near a first of said processing regions and one or more gas outputs and one or more residue outputs.



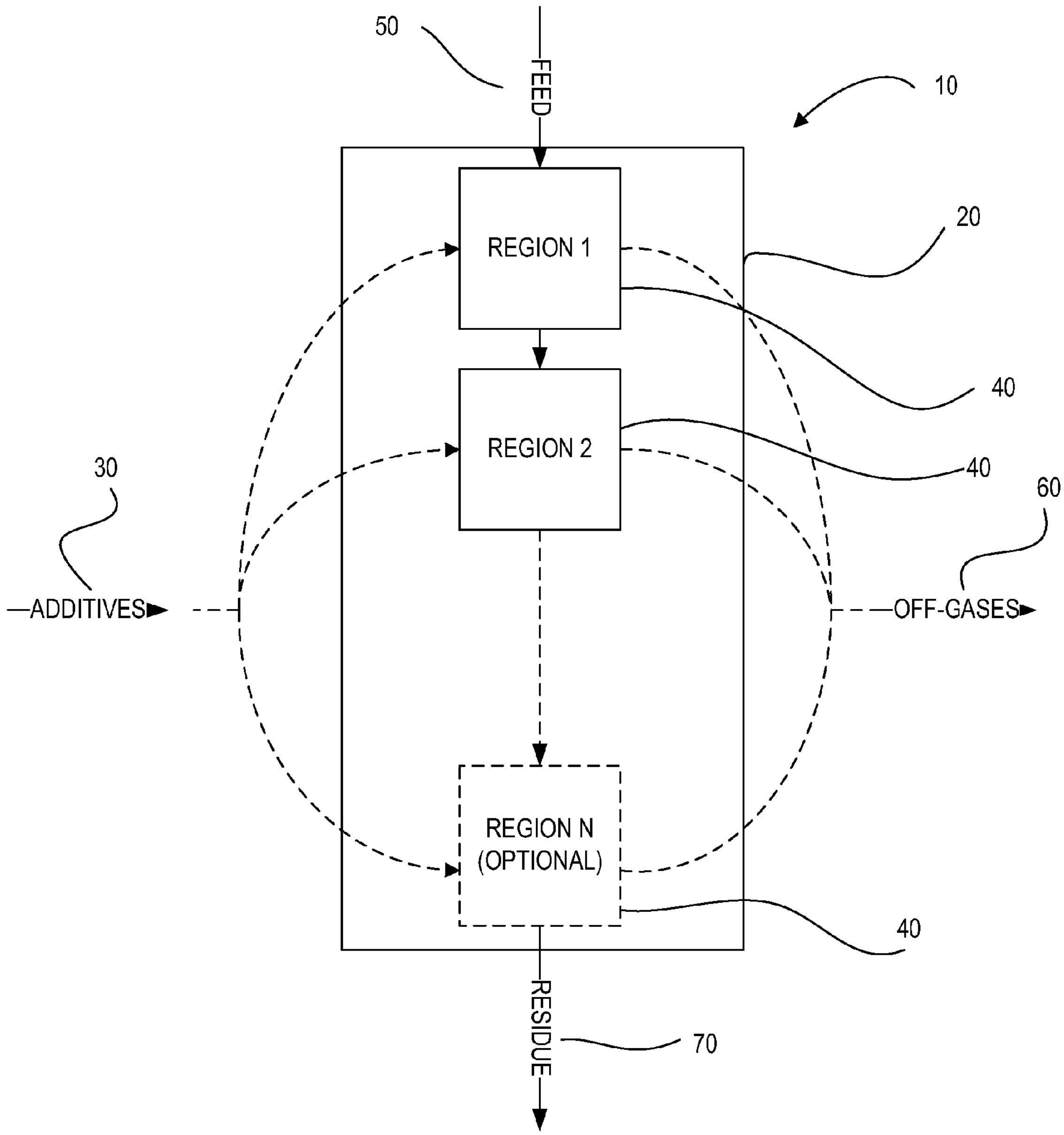

50
FEED
10
REGION 1
20
40
REGION 2
40
30
60
ADDITIVES
OFF-GASES
REGION N
(OPTIONAL)
40
RESIDUE
70

FIGURE 1

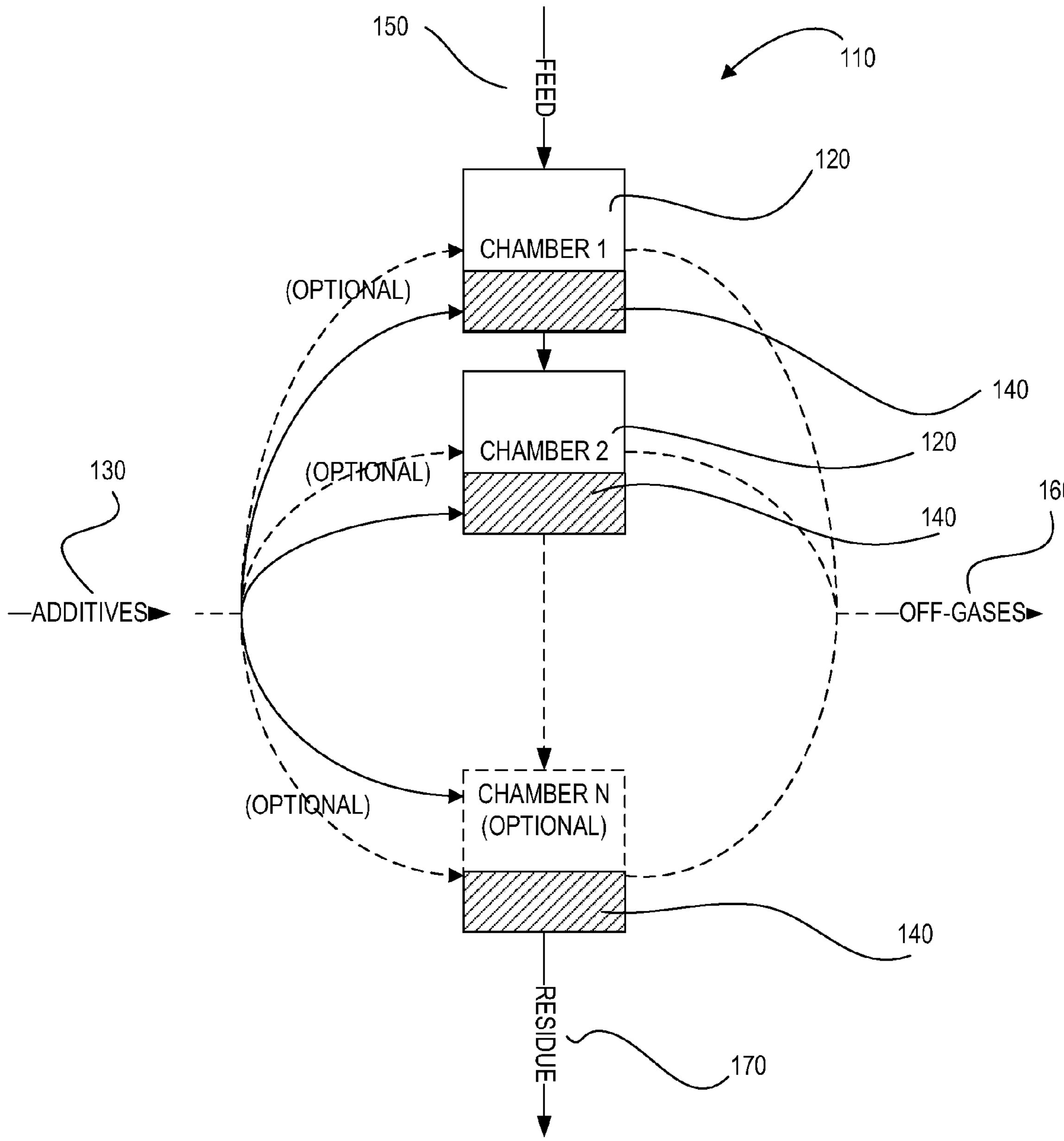

150
FEED
110
120
CHAMBER 1
(OPTIONAL)
140
CHAMBER 2
120
(OPTIONAL)
130
140
160
ADDITIVES
OFF-GASES
CHAMBER N
(OPTIONAL)
(OPTIONAL)
140
RESIDUE
170

FIGURE 2

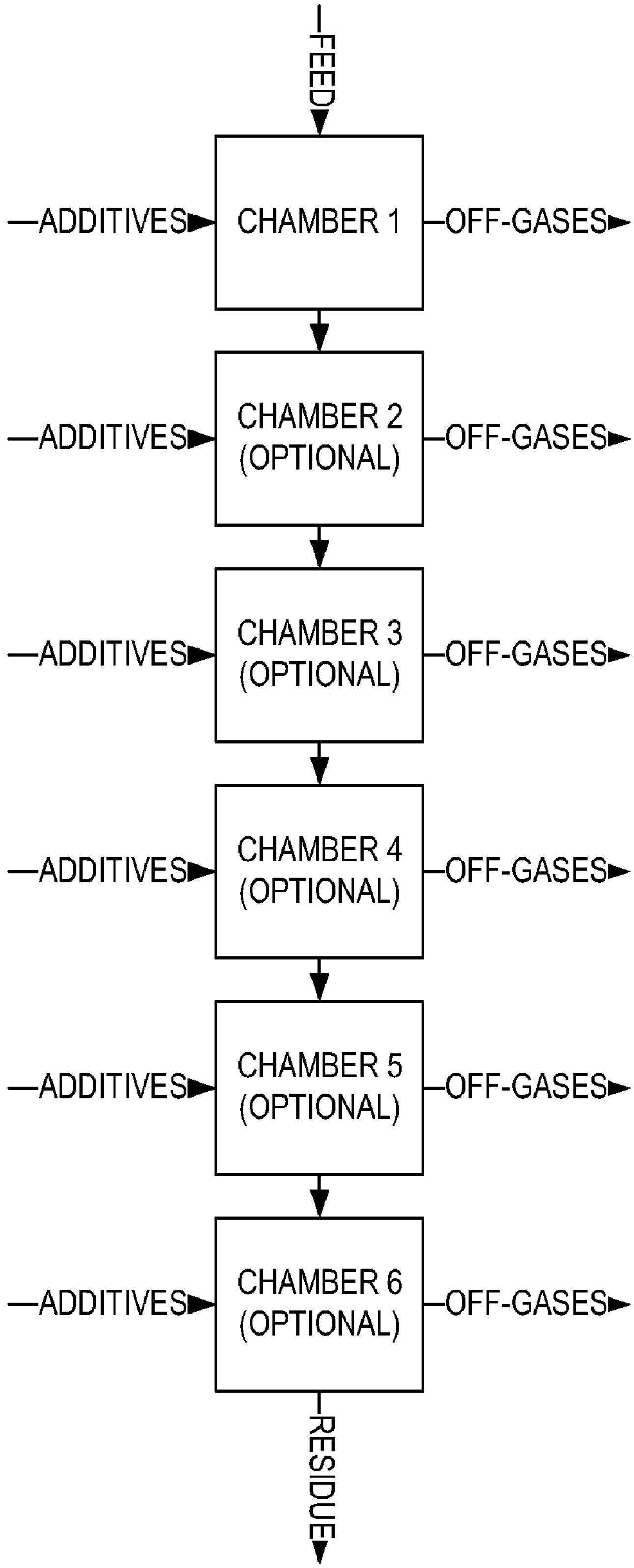

FEED
ADDITIVES
CHAMBER 1
OFF-GASES
ADDITIVES
CHAMBER 2 (OPTIONAL)
OFF-GASES
ADDITIVES
CHAMBER 3 (OPTIONAL)
OFF-GASES
ADDITIVES
CHAMBER 4 (OPTIONAL)
OFF-GASES
ADDITIVES
CHAMBER 5 (OPTIONAL)
OFF-GASES
ADDITIVES
CHAMBER 6 (OPTIONAL)
OFF-GASES
RESIDUE

FIGURE 3

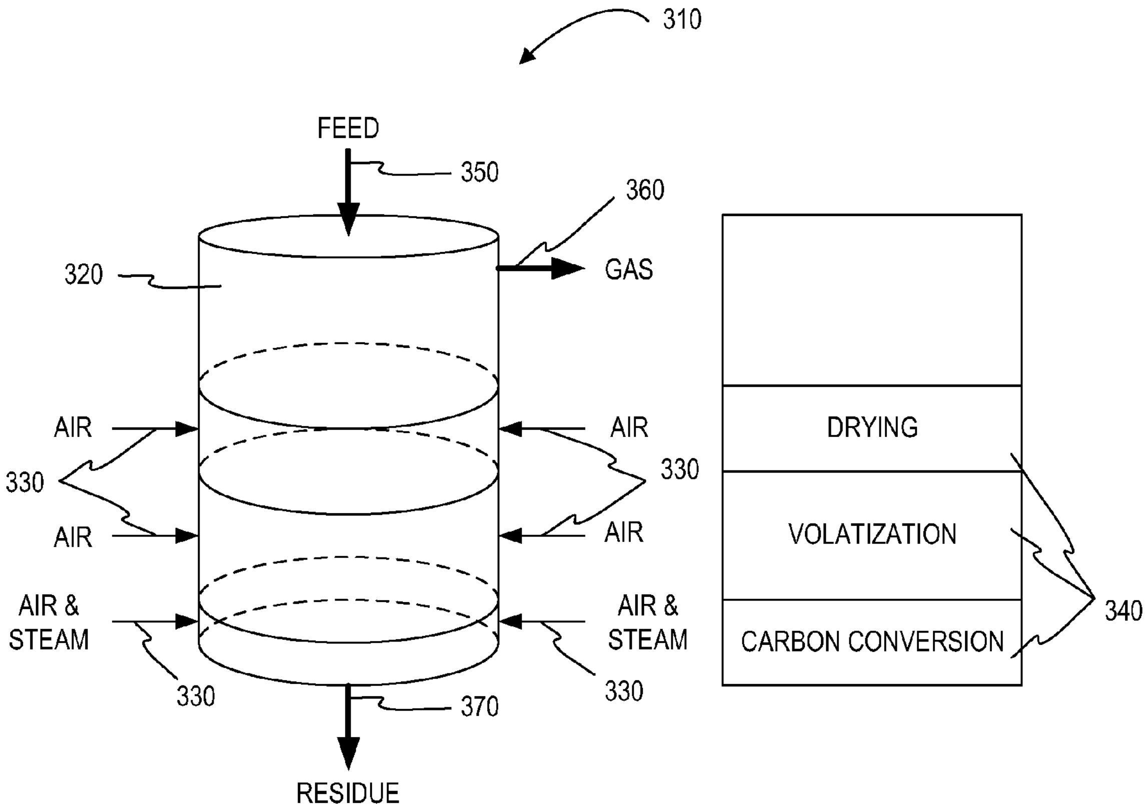

310
FEED
350
360
GAS
320
AIR
AIR
330
330
AIR
AIR
AIR &
STEAM
AIR &
STEAM
330
330
370
RESIDUE
DRYING
VOLATIZATION
CARBON CONVERSION
340

FIGURE 4

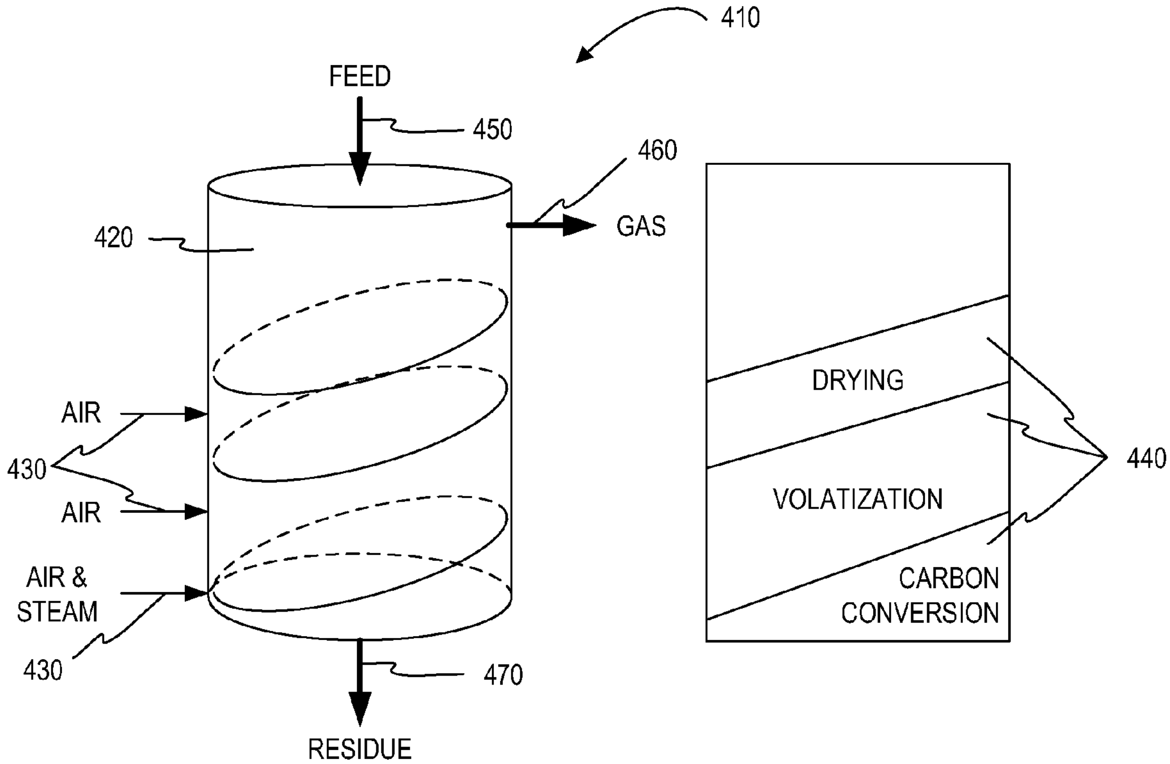

410
FEED
450
460
GAS
420
DRYING
AIR
430
440
AIR
VOLATIZATION
AIR &
STEAM
CARBON
CONVERSION
430
470
RESIDUE

FIGURE 5

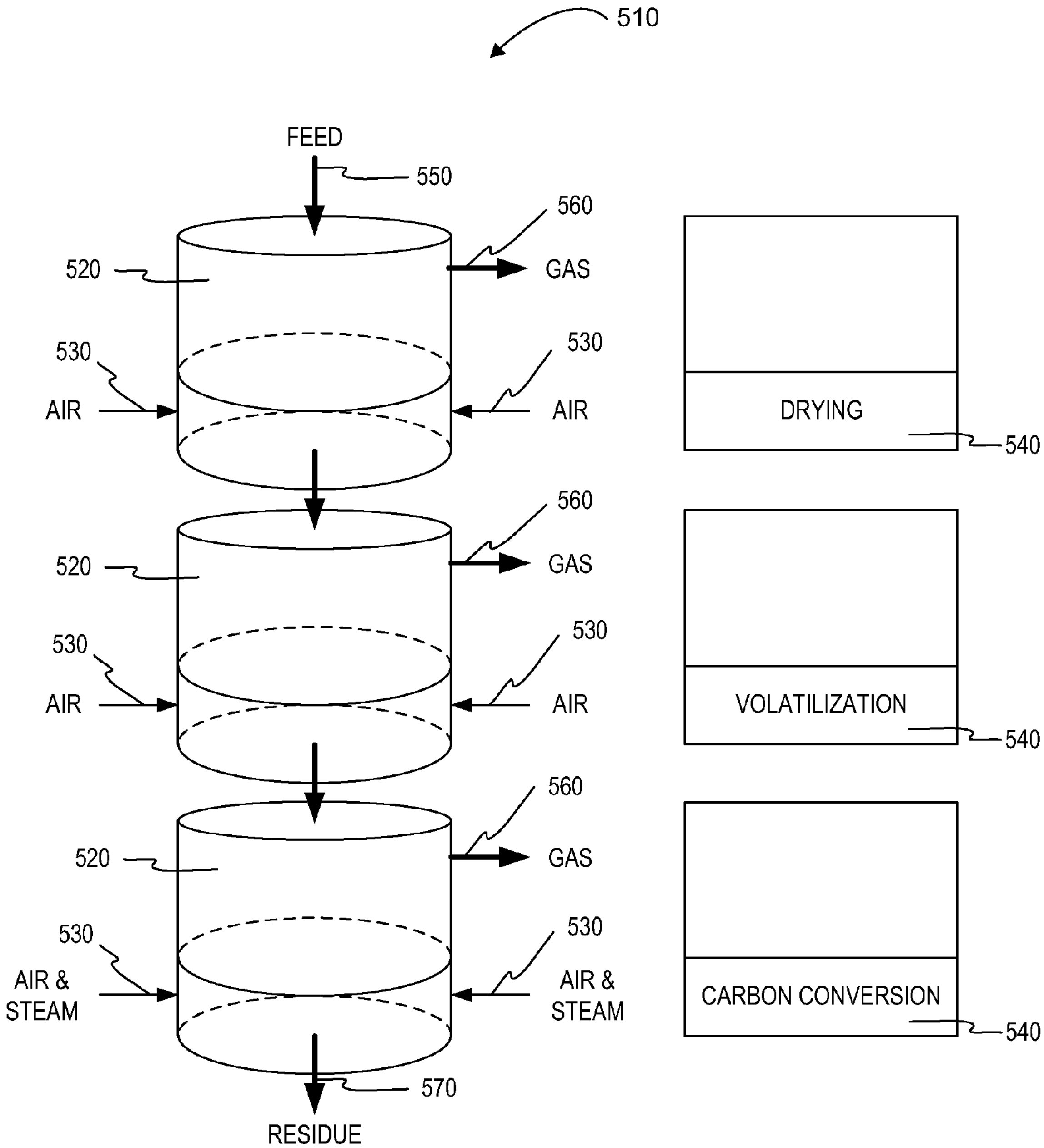

510
FEED
550
560
GAS
520
530
AIR
530
AIR
DRYING
540
560
GAS
520
530
AIR
530
AIR
VOLATILIZATION
540
560
GAS
520
530
AIR &
STEAM
530
AIR &
STEAM
CARBON CONVERSION
540
570
RESIDUE

FIGURE 6

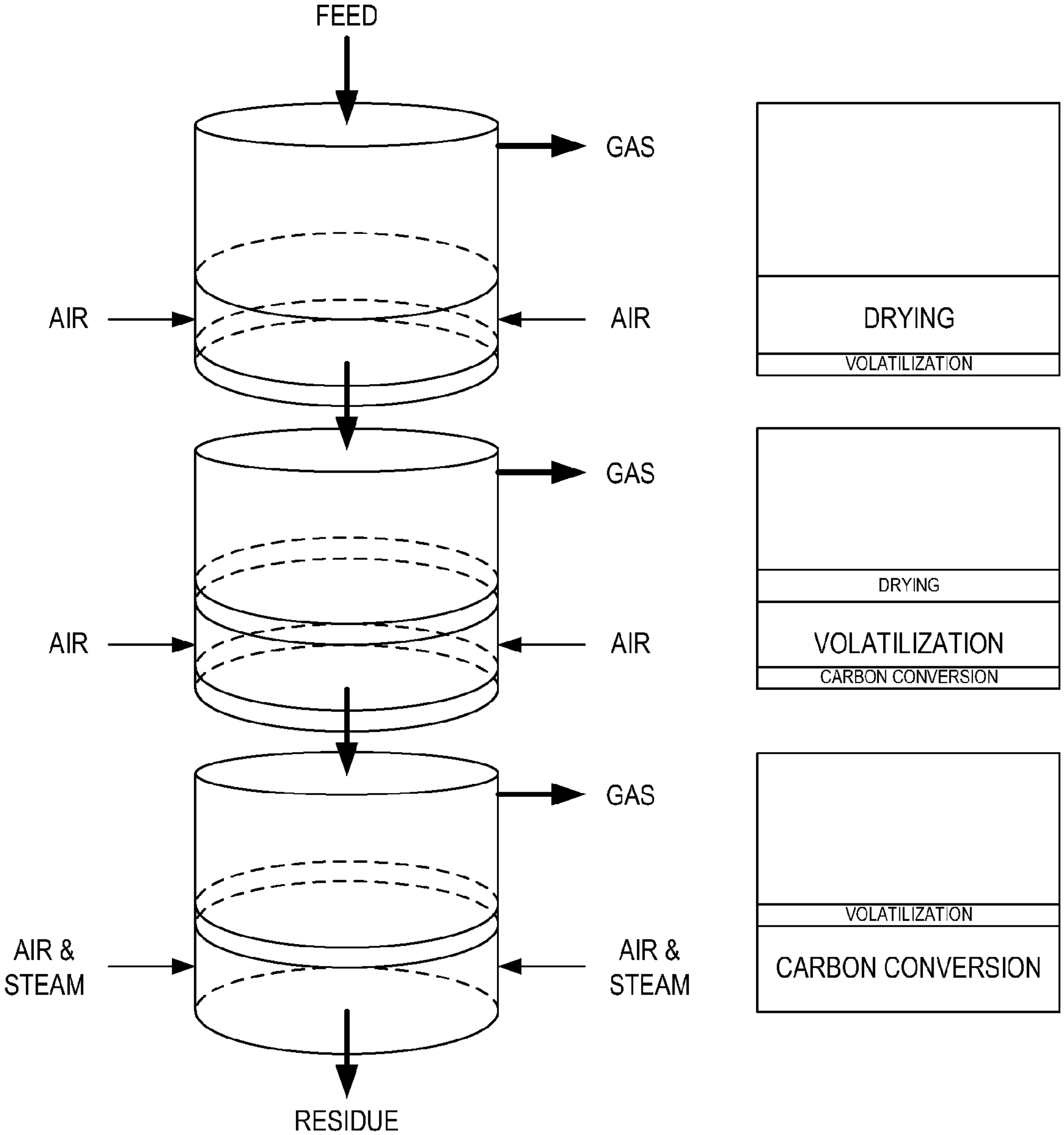

FEED
GAS
AIR
AIR
DRYING
VOLATILIZATION
GAS
AIR
AIR
DRYING
VOLATILIZATION
CARBON CONVERSION
GAS
AIR & STEAM
AIR & STEAM
VOLATILIZATION
CARBON CONVERSION
RESIDUE

FIGURE 7

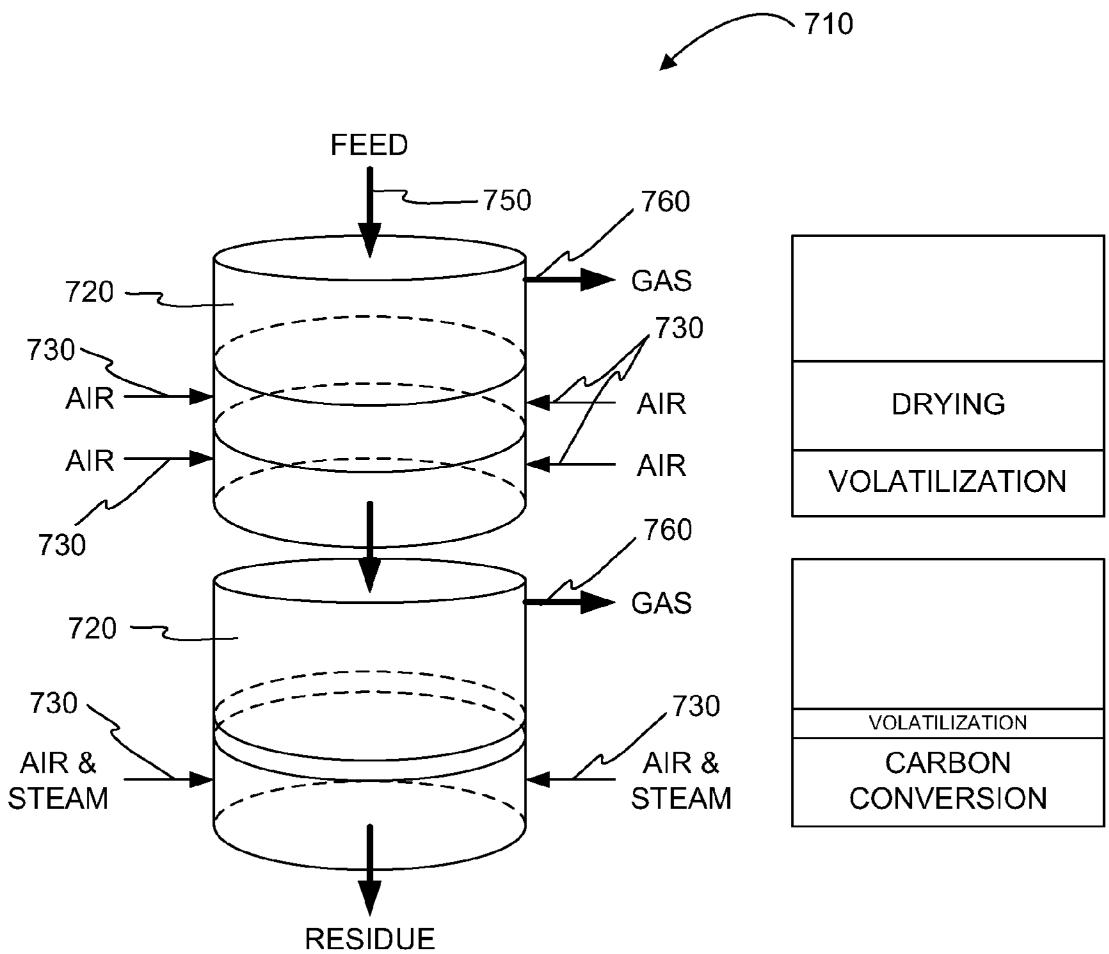

710
FEED
750
760
GAS
720
730
AIR
AIR
730
AIR
AIR
730
760
GAS
720
730
AIR &
STEAM
730
AIR &
STEAM
RESIDUE
DRYING
VOLATILIZATION
VOLATILIZATION
CARBON
CONVERSION

FIGURE 8

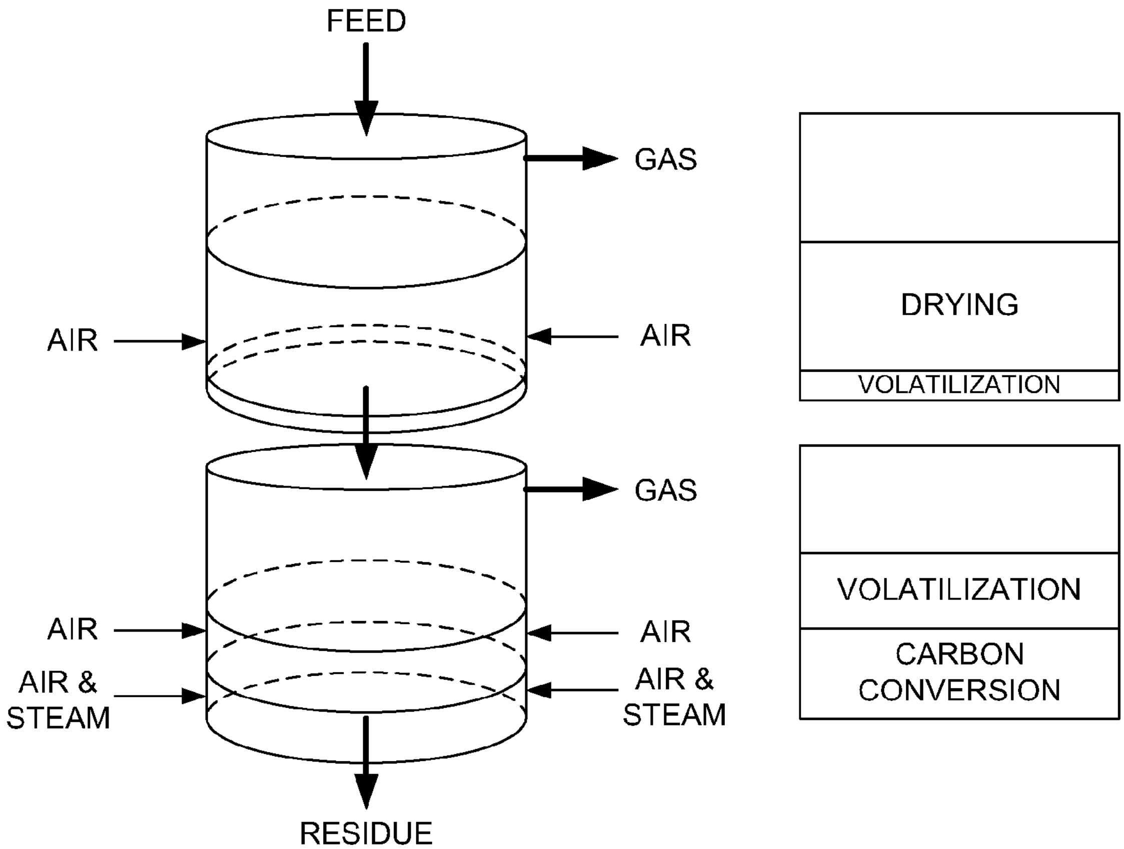

FEED
GAS
AIR
AIR
DRYING
VOLATILIZATION
GAS
AIR
AIR
AIR &
STEAM
AIR &
STEAM
VOLATILIZATION
CARBON
CONVERSION
RESIDUE

FIGURE 9

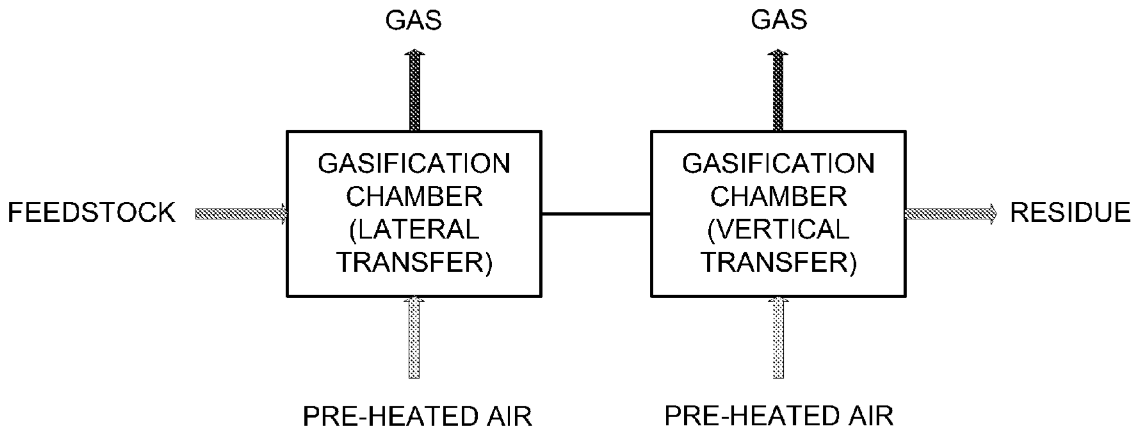

GAS
GAS
FEEDSTOCK
GASIFICATION CHAMBER (LATERAL TRANSFER)
GASIFICATION CHAMBER (VERTICAL TRANSFER)
RESIDUE
PRE-HEATED AIR
PRE-HEATED AIR

FIGURE 10

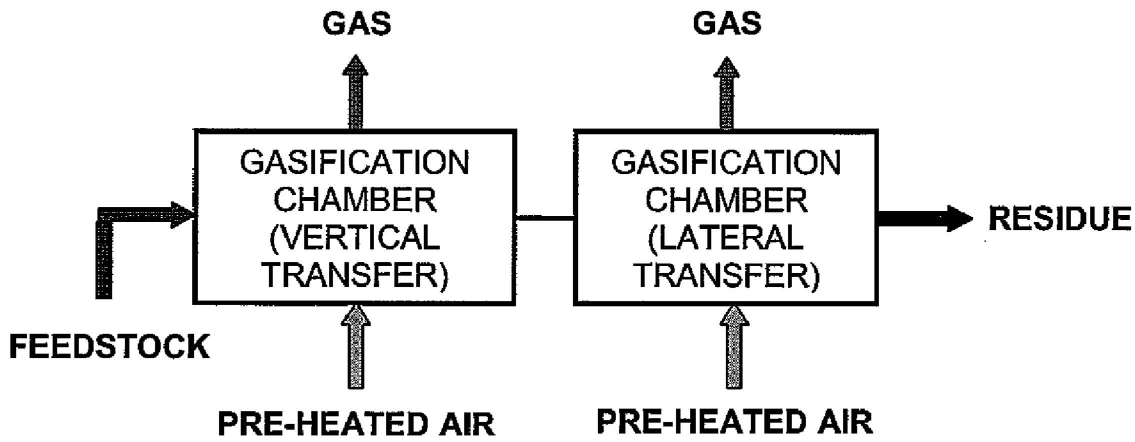

GAS
GAS
GASIFICATION CHAMBER (VERTICAL TRANSFER)
GASIFICATION CHAMBER (LATERAL TRANSFER)
RESIDUE
FEEDSTOCK
PRE-HEATED AIR
PRE-HEATED AIR

Figure 11

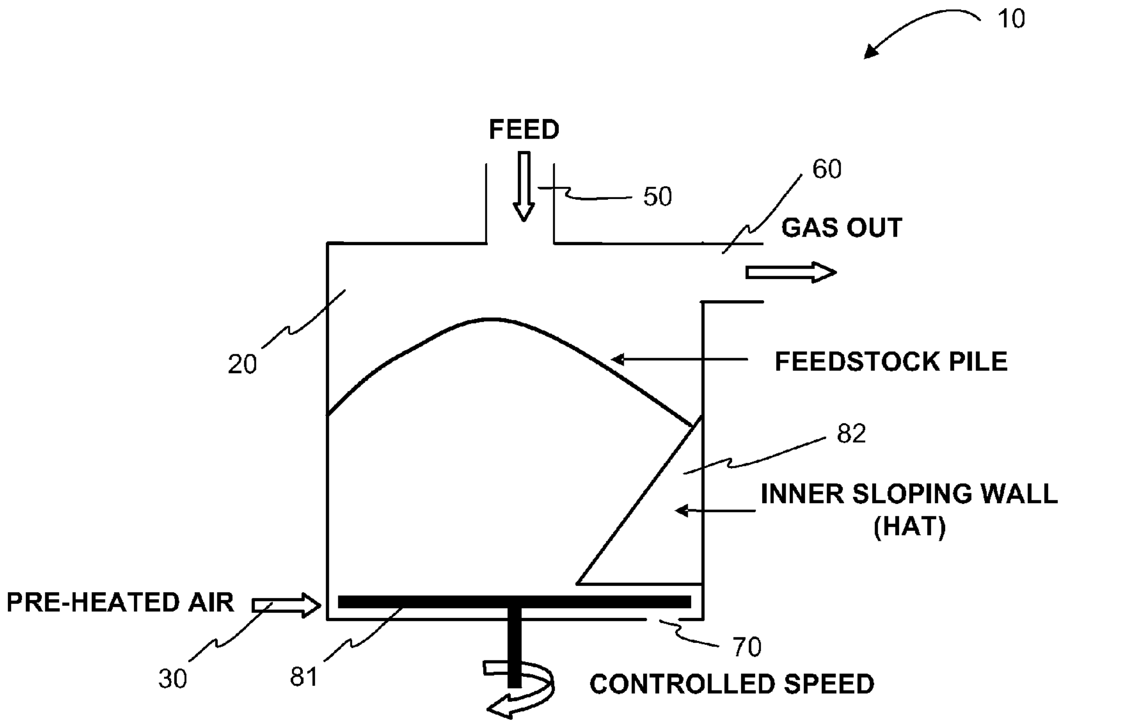


Figure 12A

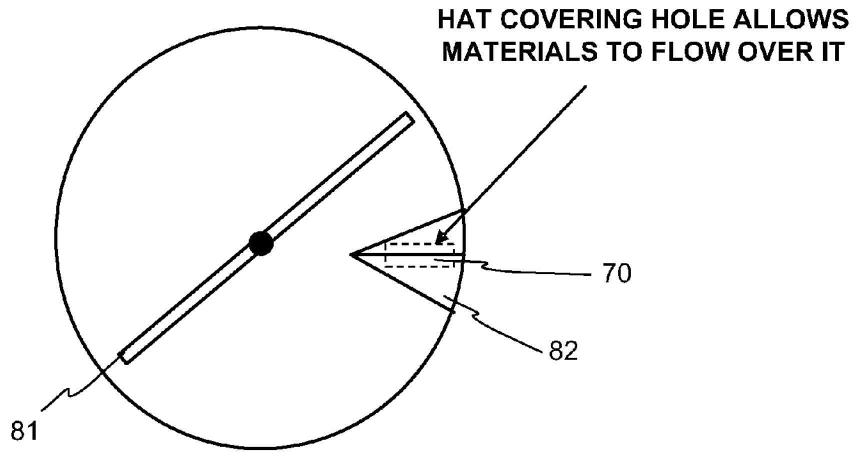


FIGURE 12B

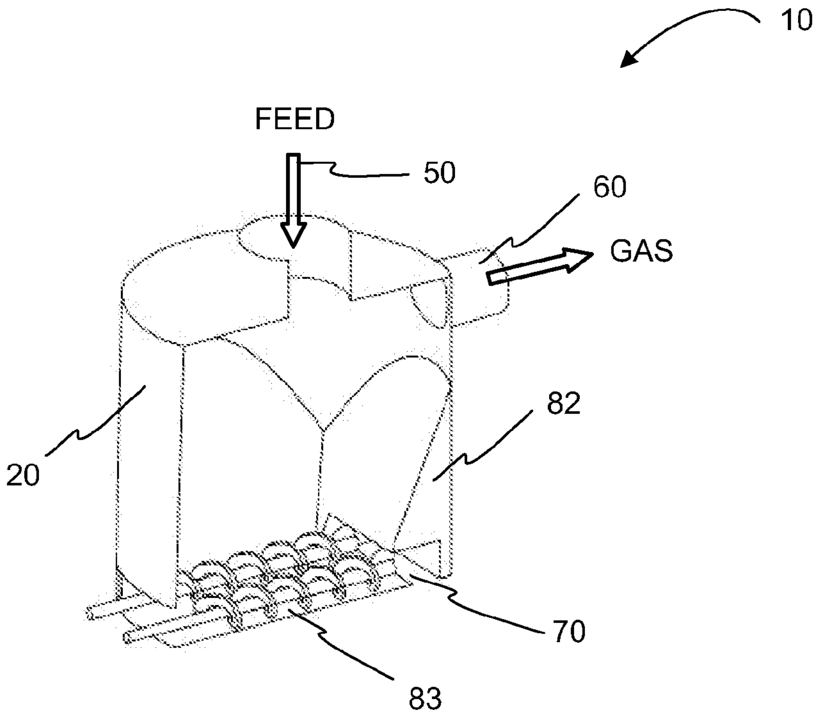


FIGURE 13A

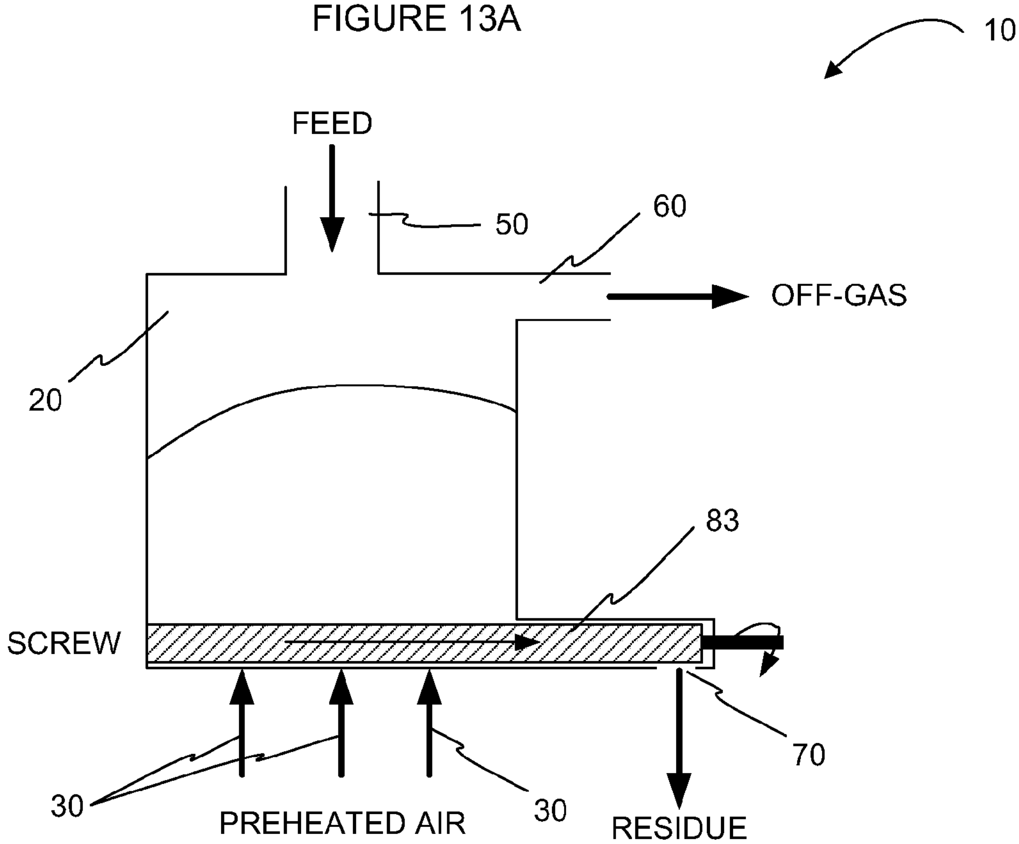


FIGURE 13B

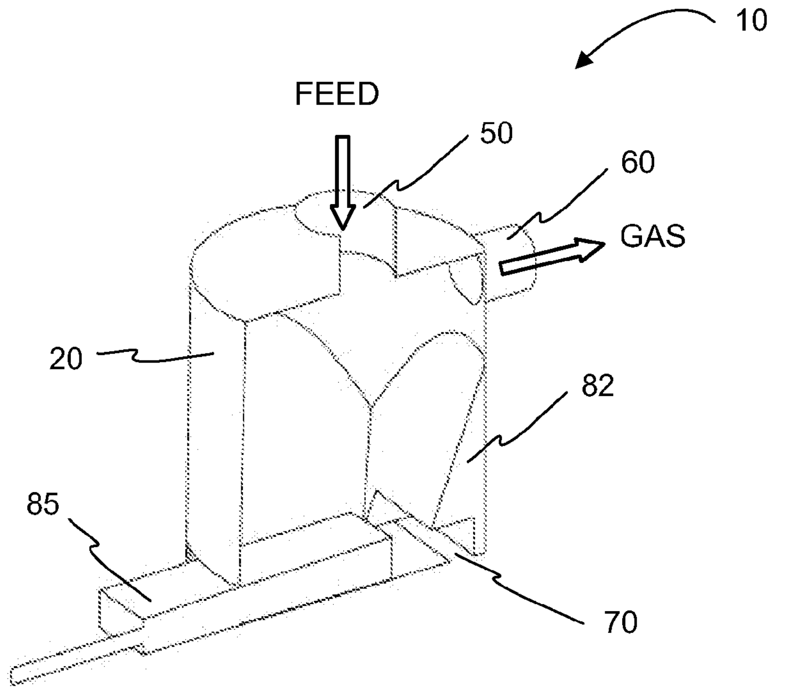


FIGURE 14A

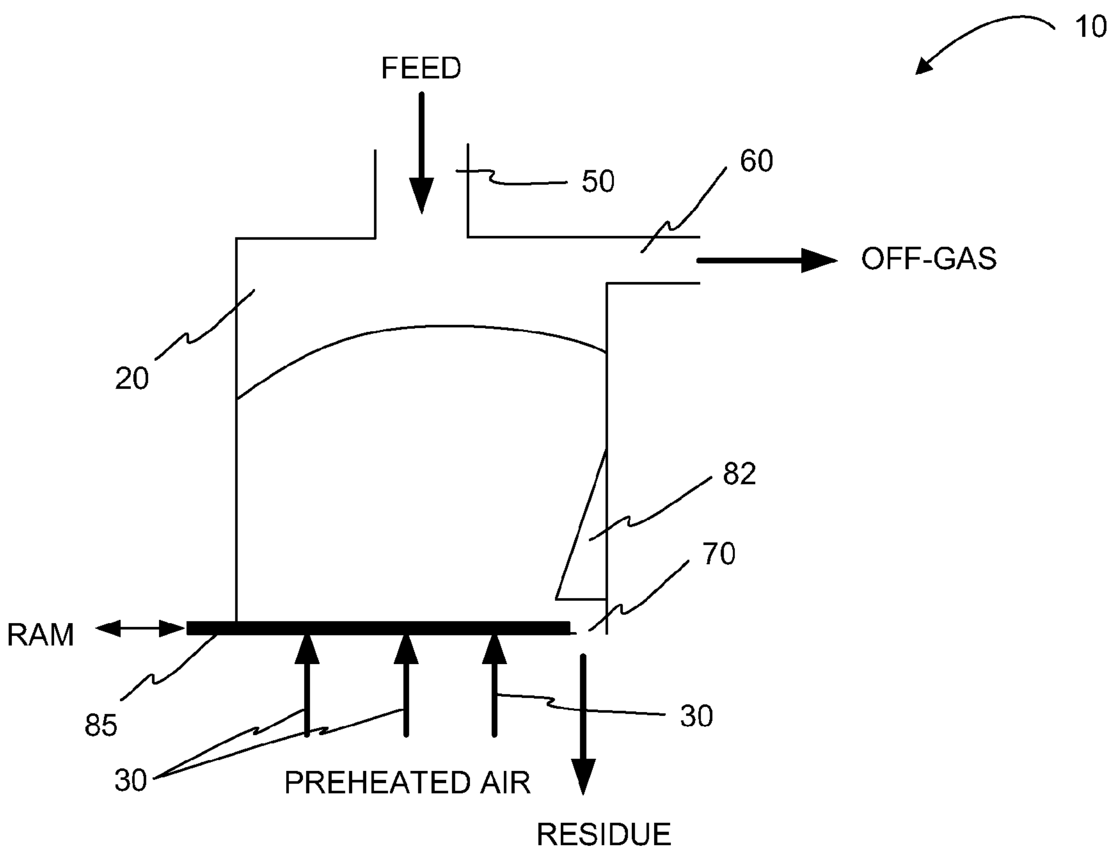


FIGURE 14B

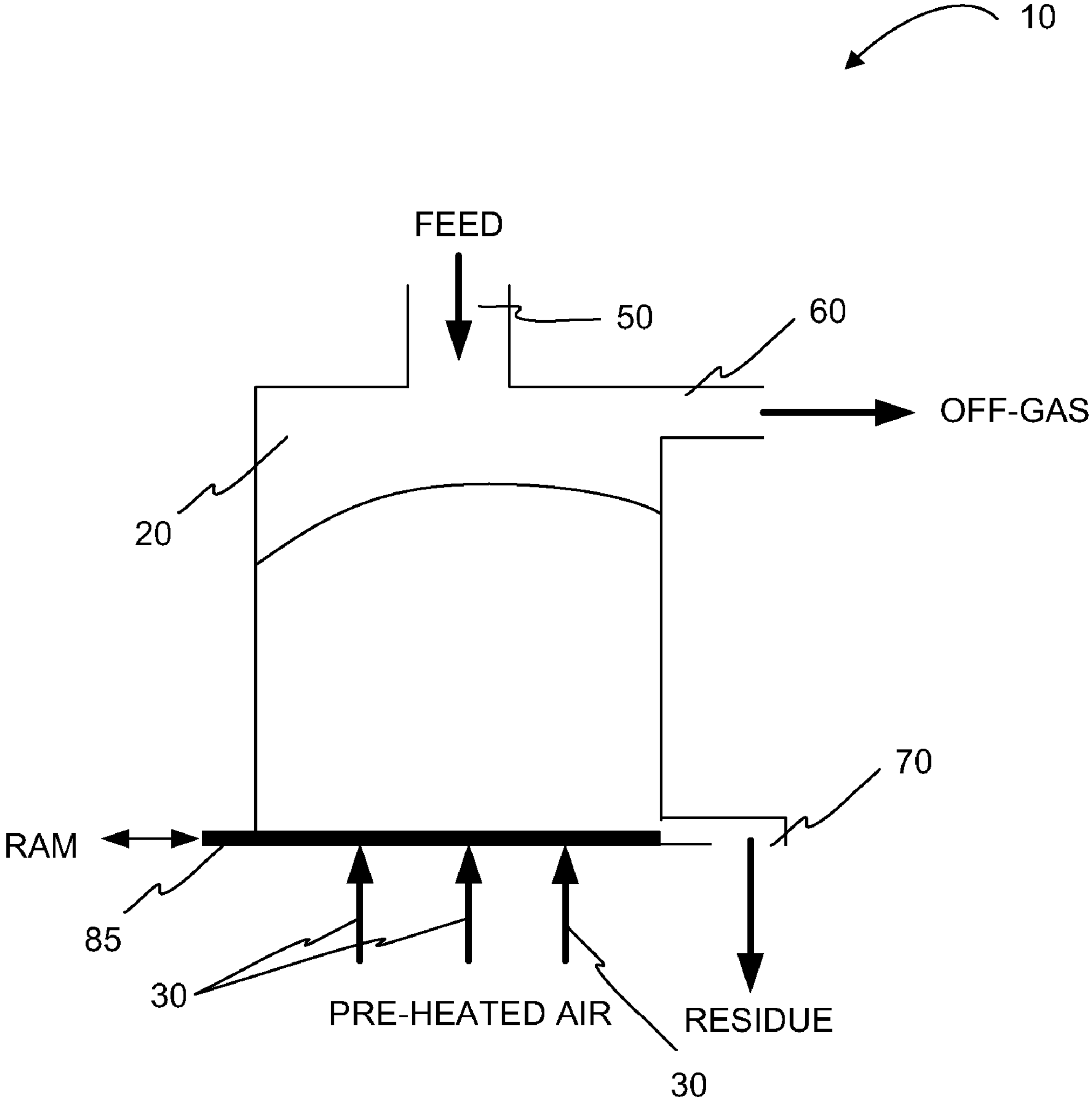


FIGURE 14C

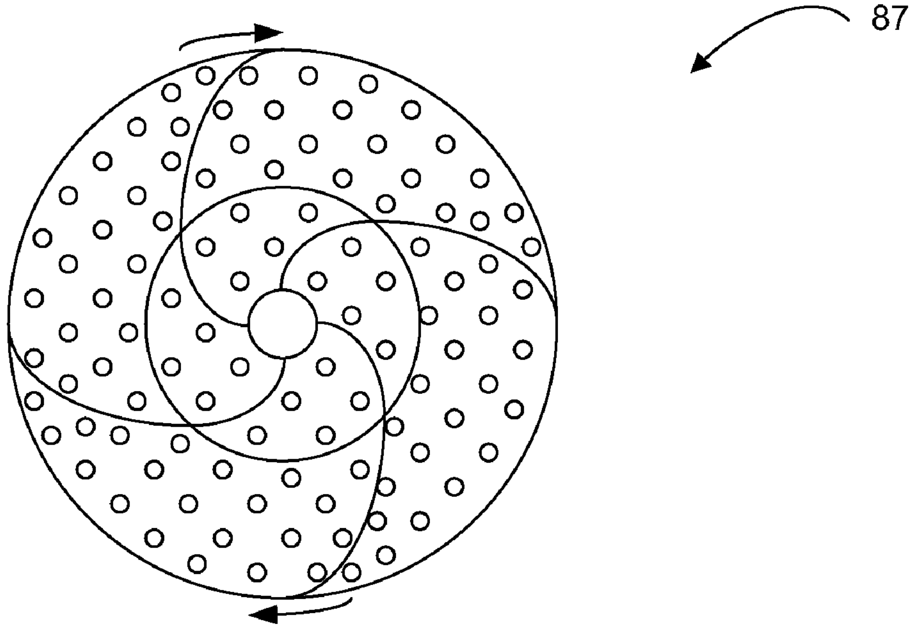


FIGURE 15A

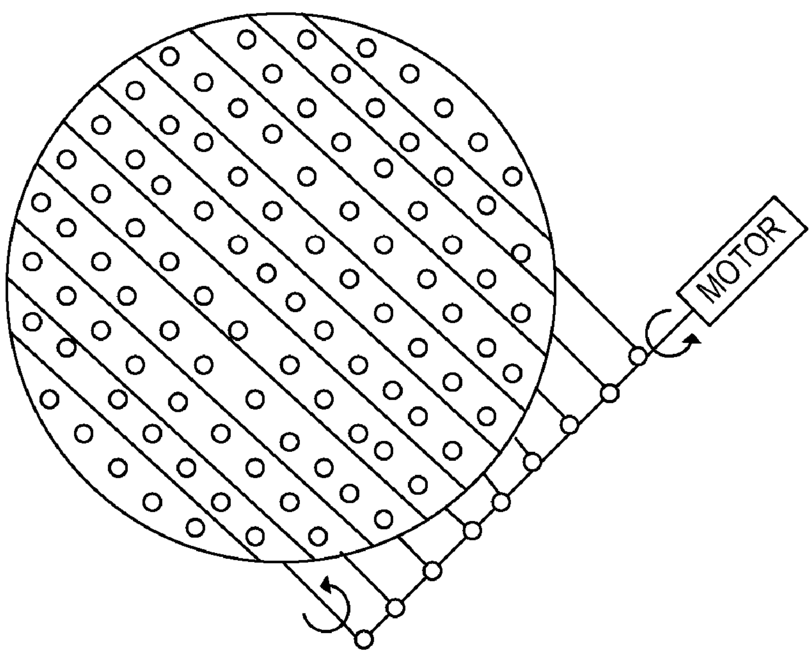


FIGURE 15B

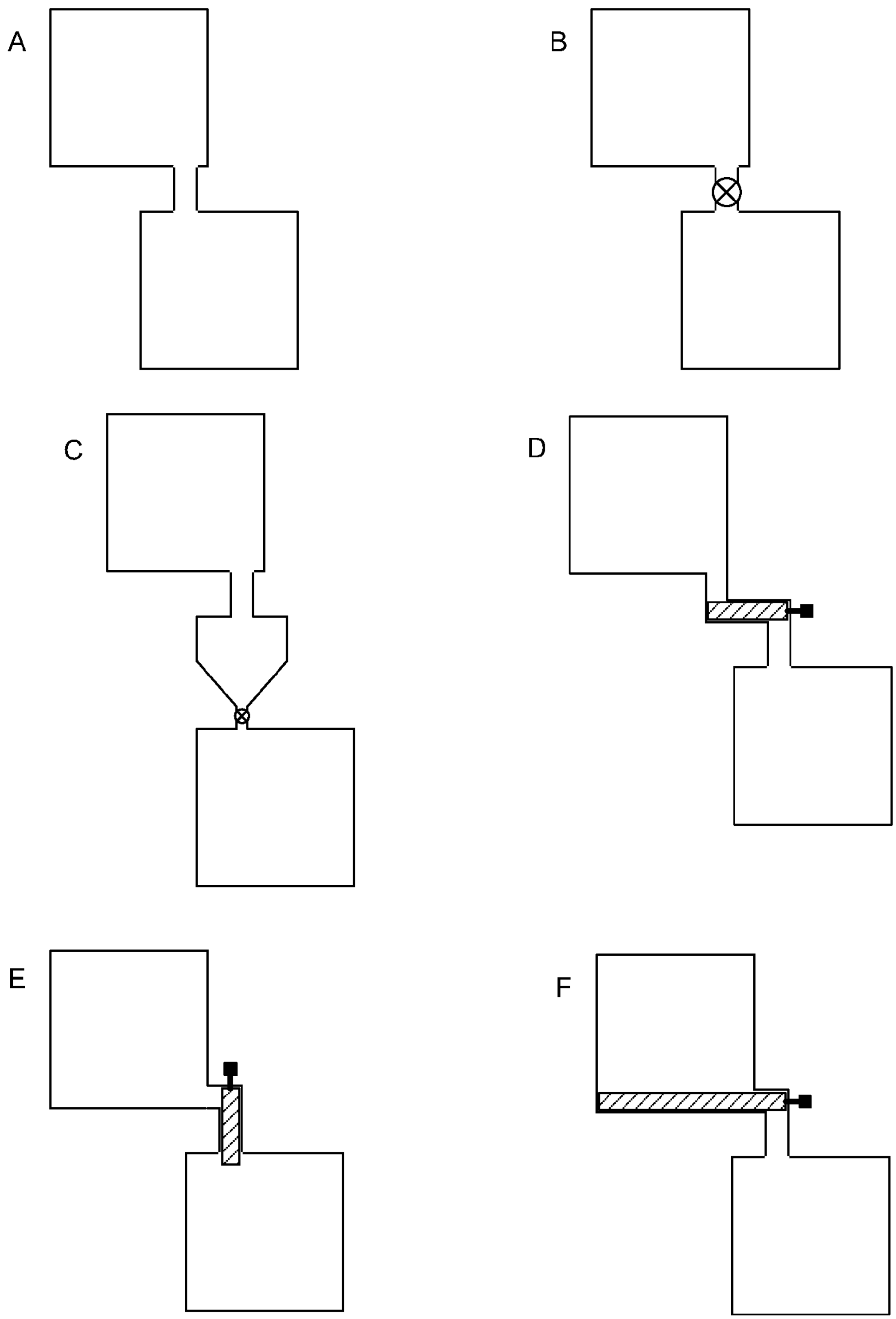


FIGURE 16A

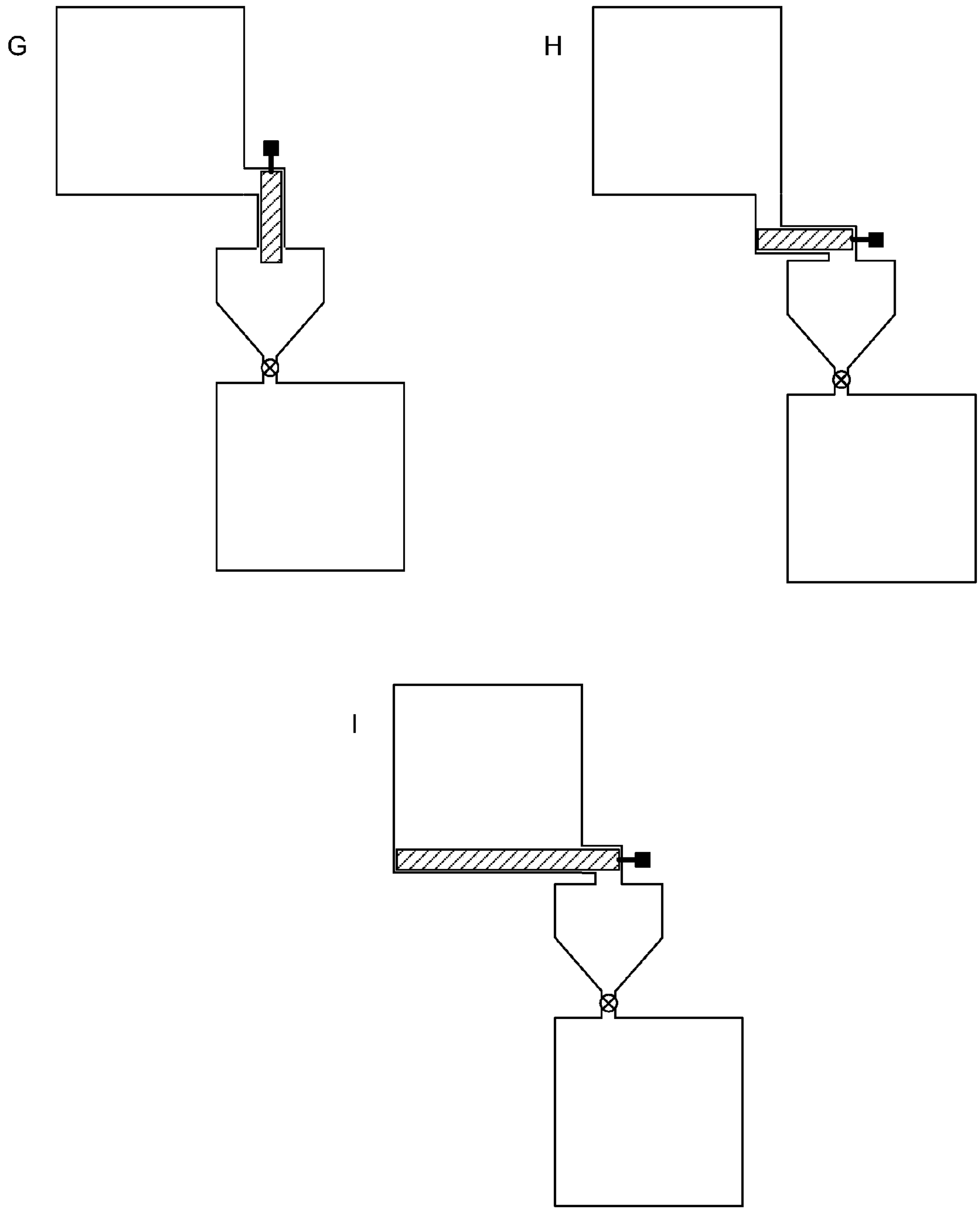


FIGURE 16B

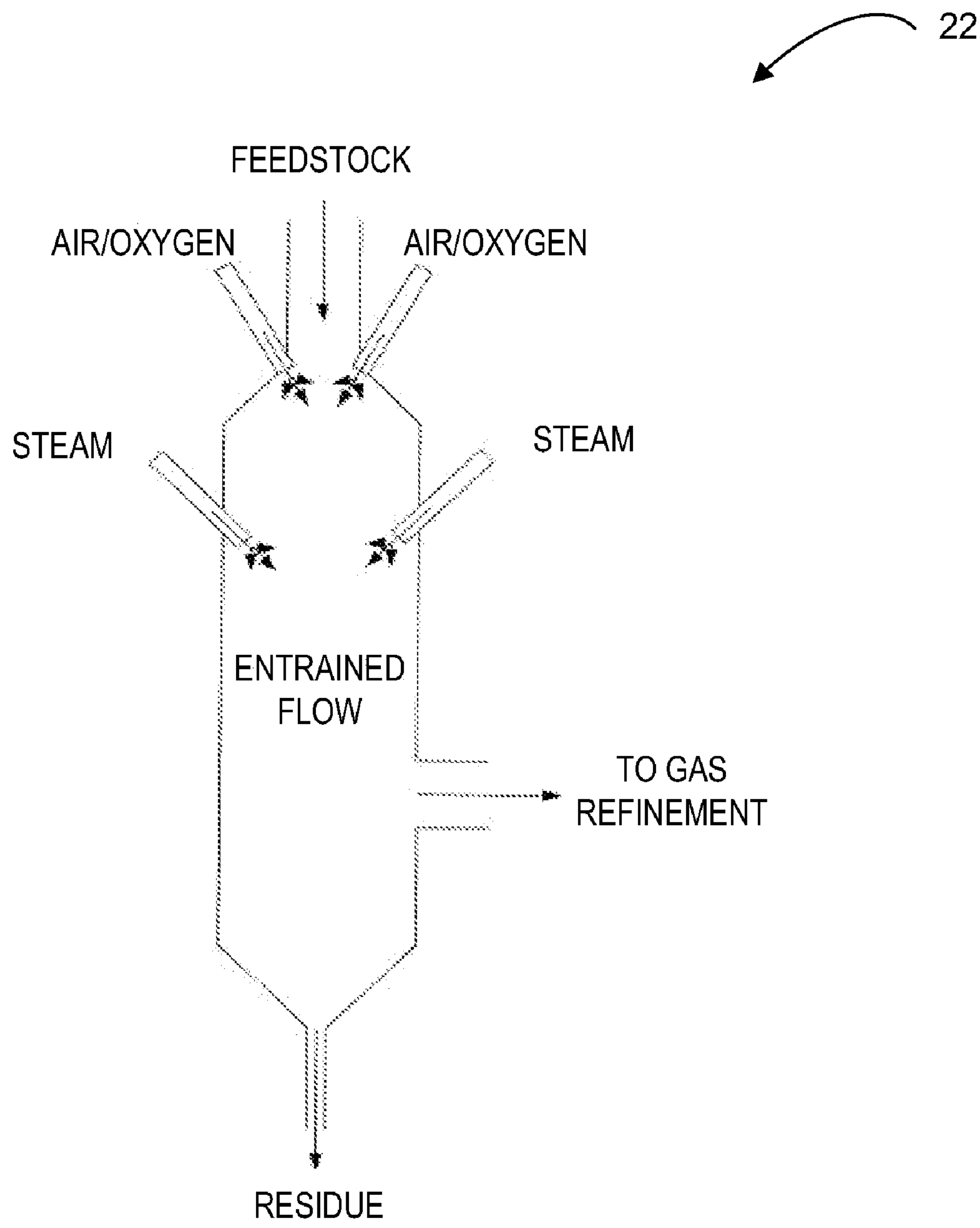

22
FEEDSTOCK
AIR/OXYGEN
AIR/OXYGEN
STEAM
STEAM
ENTRAINED FLOW
TO GAS REFINEMENT
RESIDUE

FIGURE 17

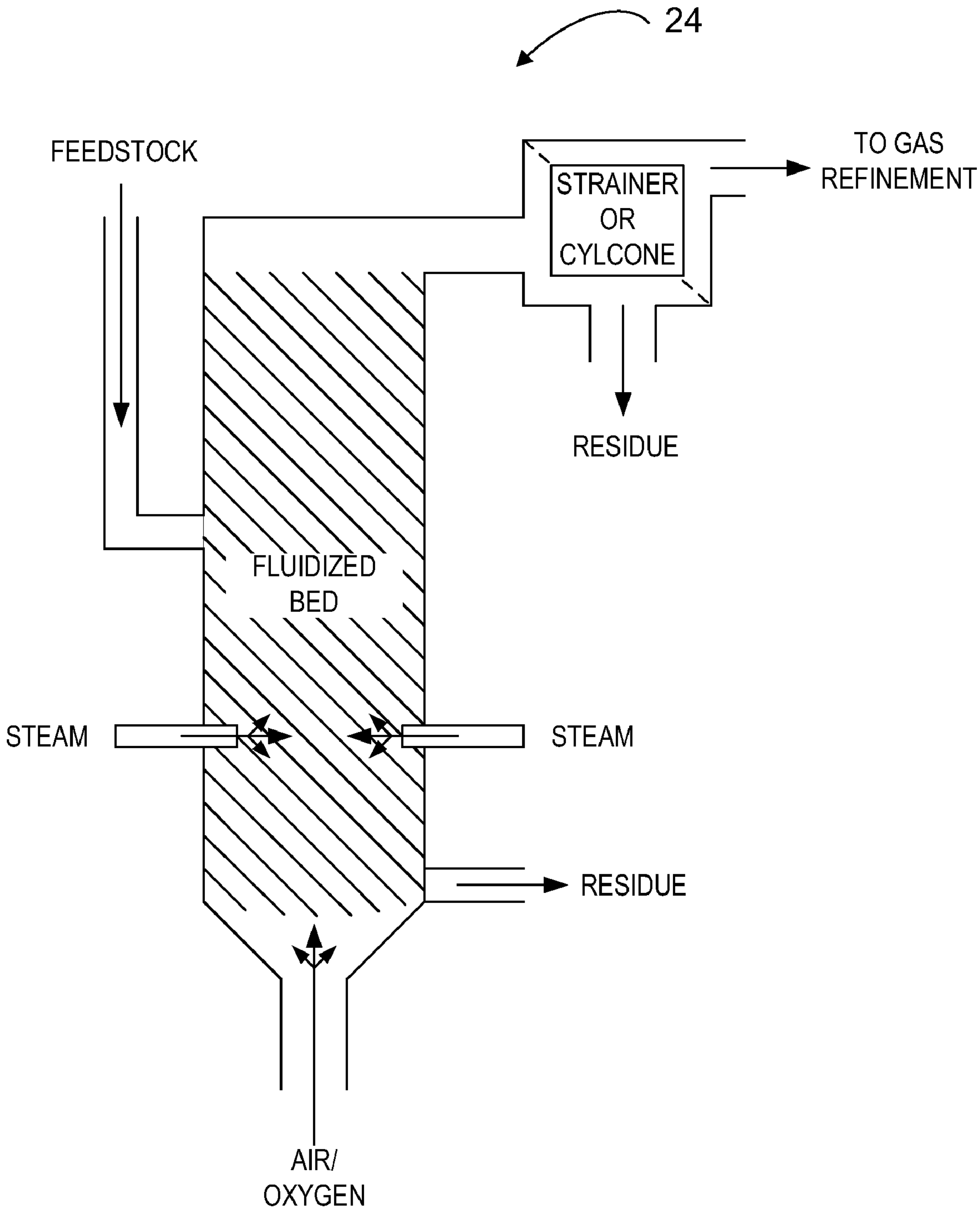

24
FEEDSTOCK
STRAINER
OR
CYLCONE
TO GAS
REFINEMENT
RESIDUE
FLUIDIZED
BED
STEAM
STEAM
RESIDUE
AIR/
OXYGEN

FIGURE 18

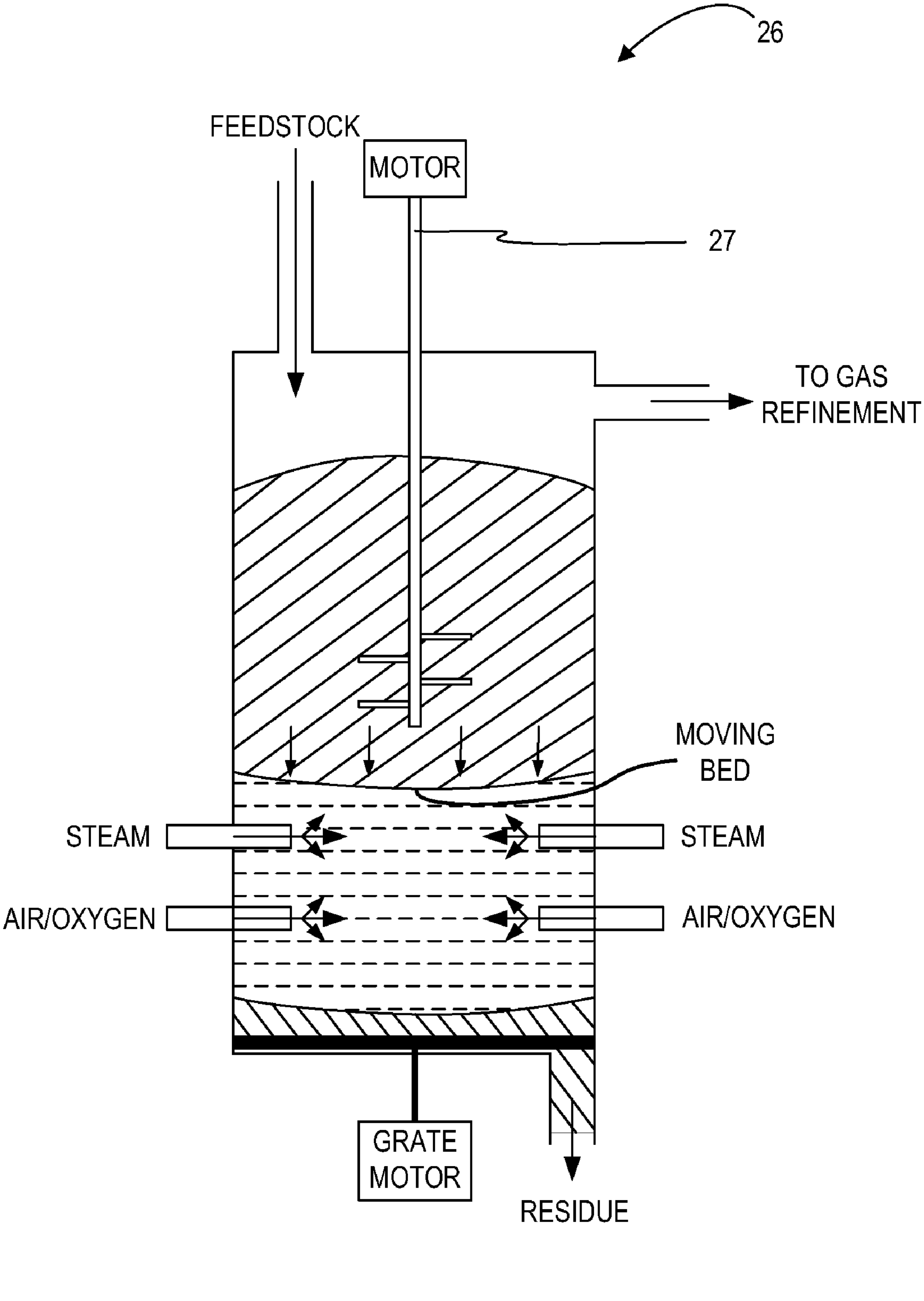

26
FEEDSTOCK
MOTOR
27
TO GAS
REFINEMENT
MOVING
BED
STEAM
STEAM
AIR/OXYGEN
AIR/OXYGEN
GRATE
MOTOR
RESIDUE

FIGURE 19

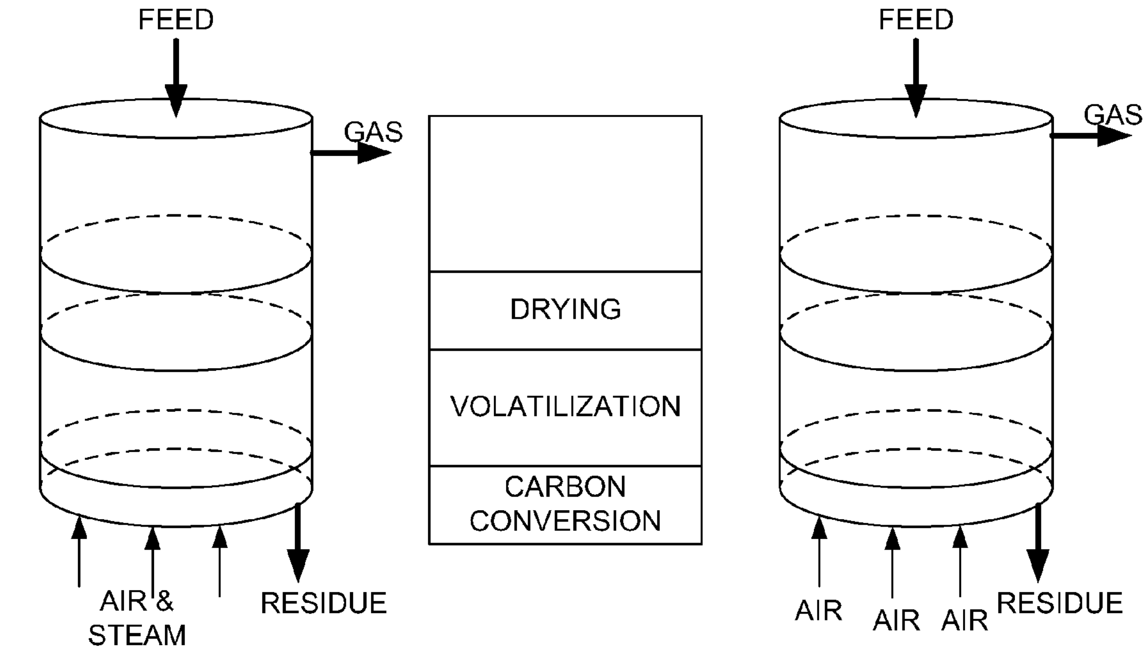


FIGURE 20A

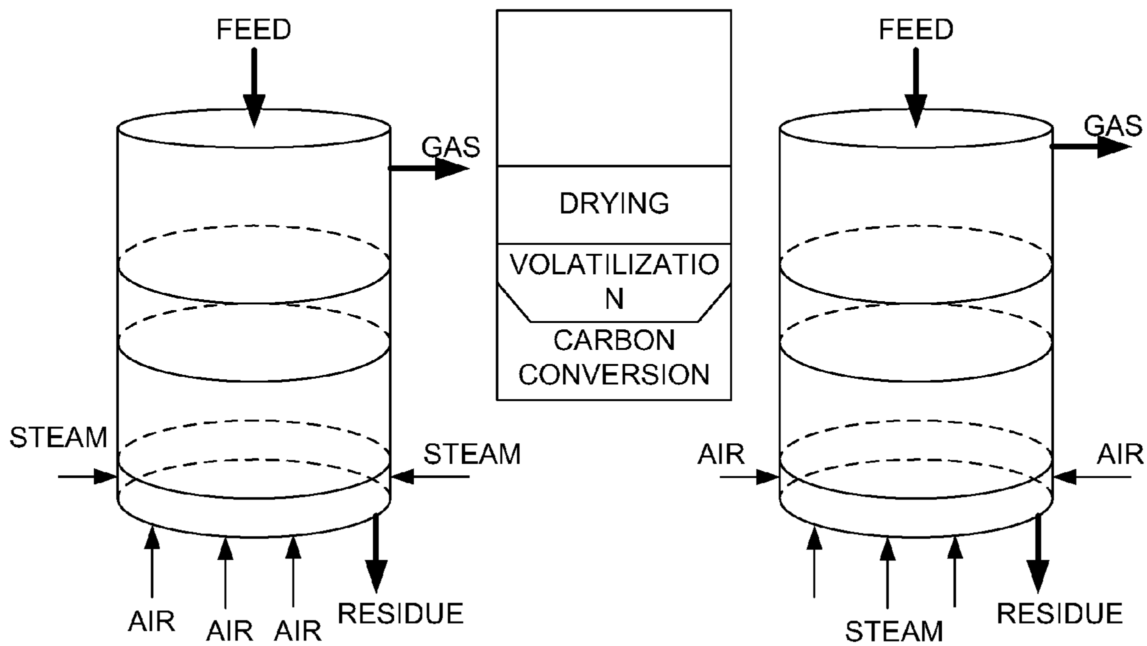


FIGURE 20B

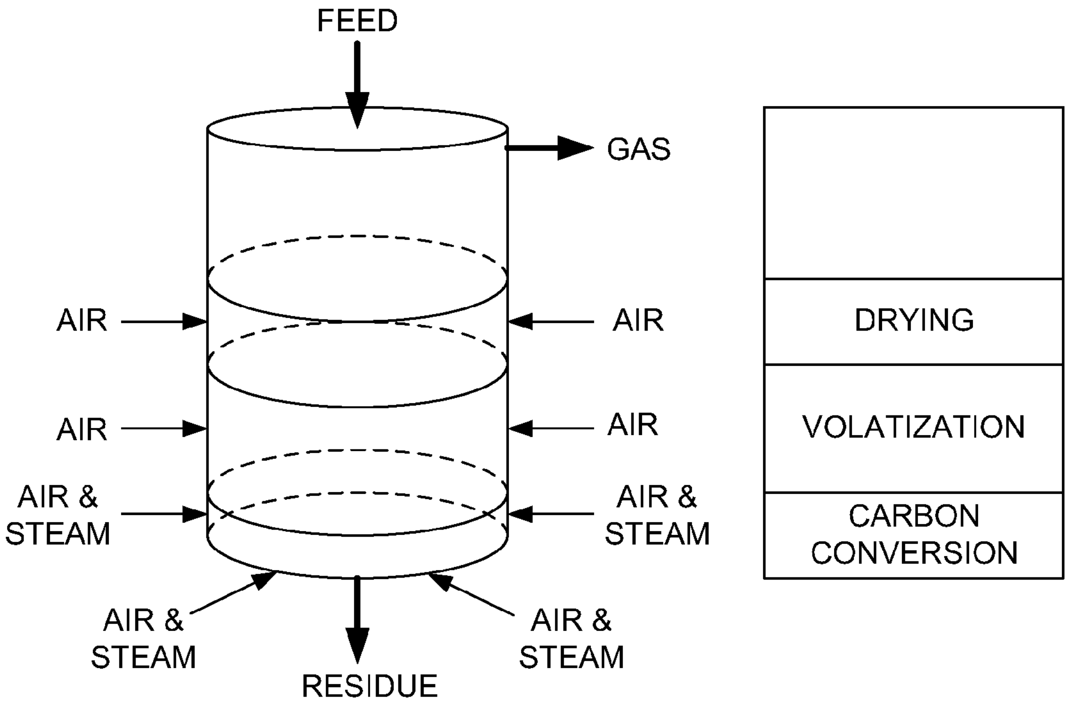


FIGURE 20C

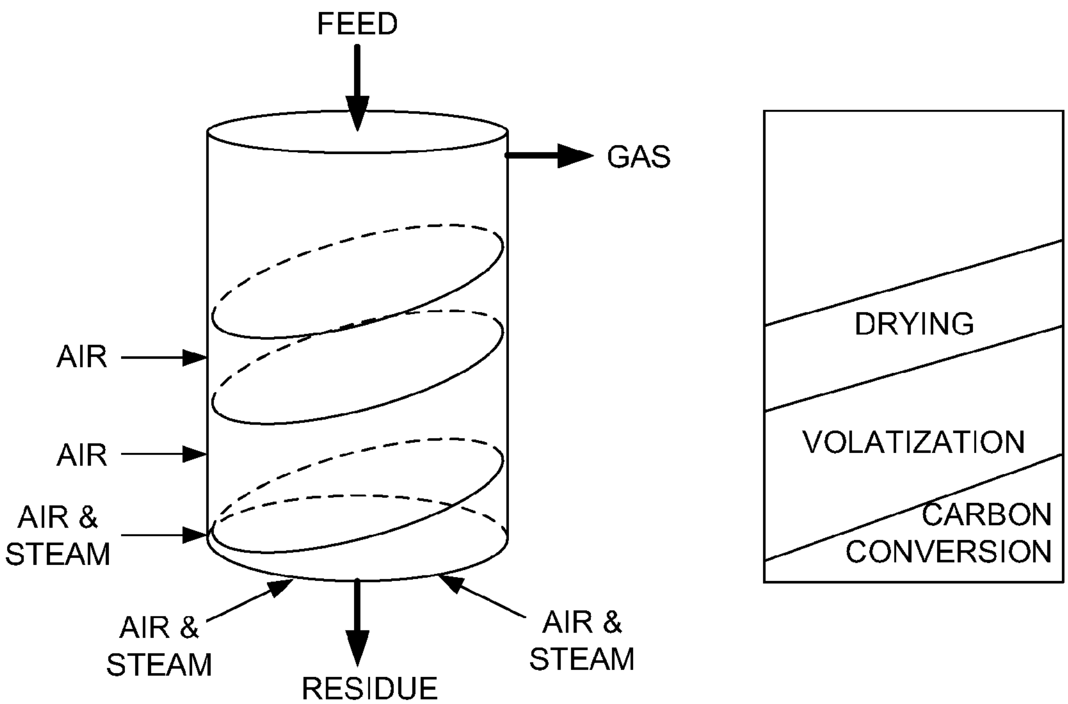


FIGURE 20D

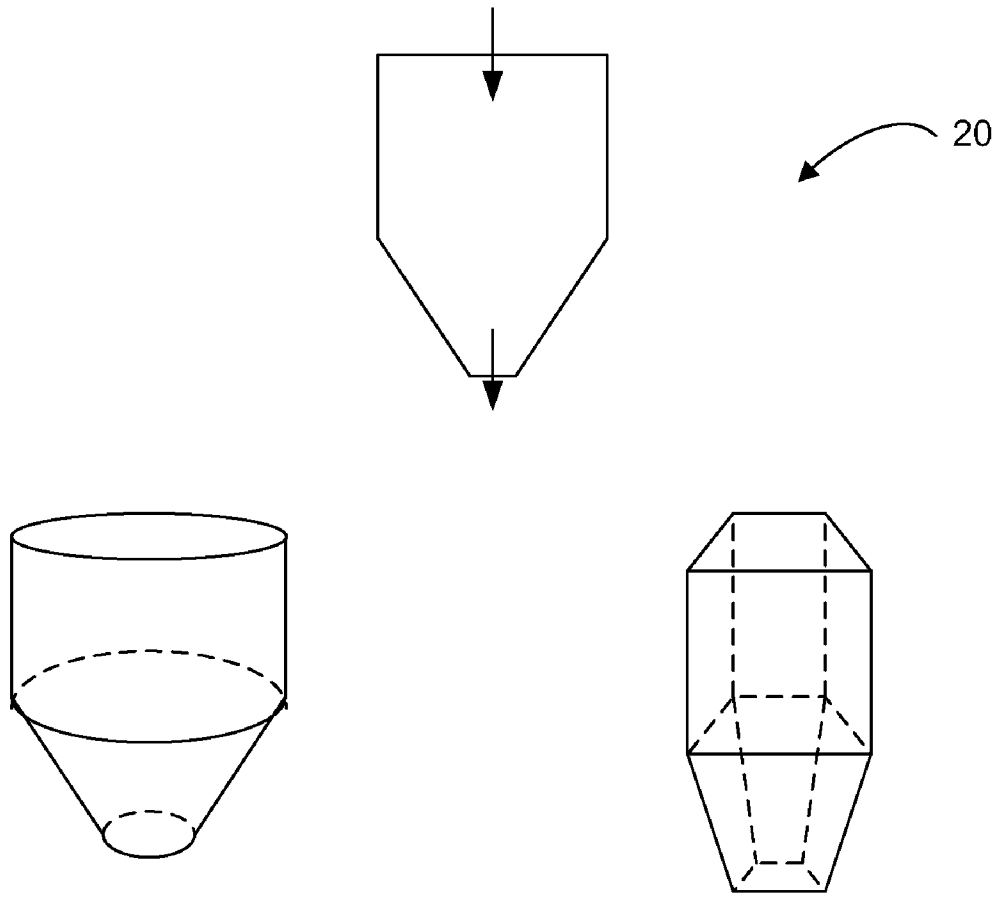


FIGURE 21A

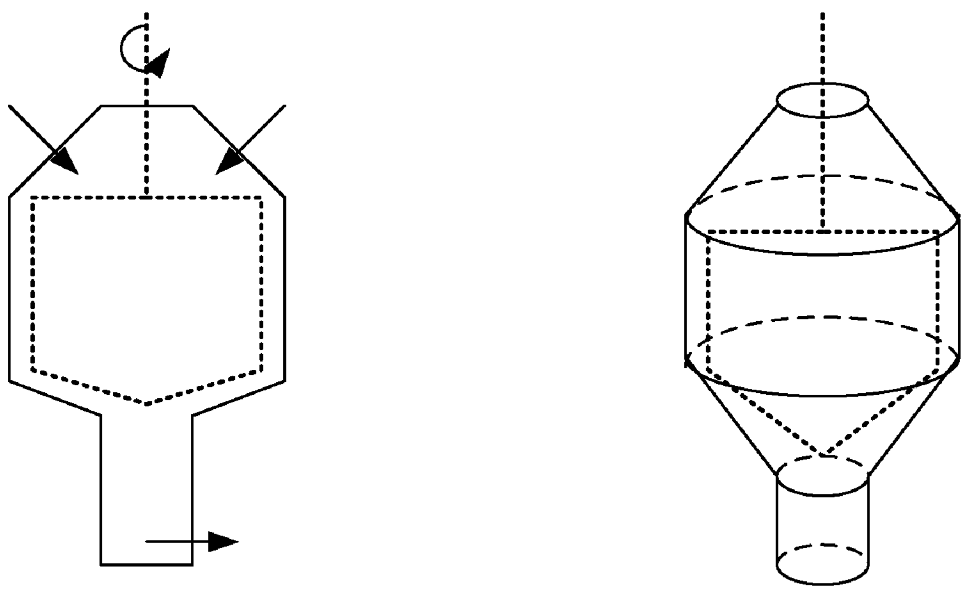


FIGURE 21B

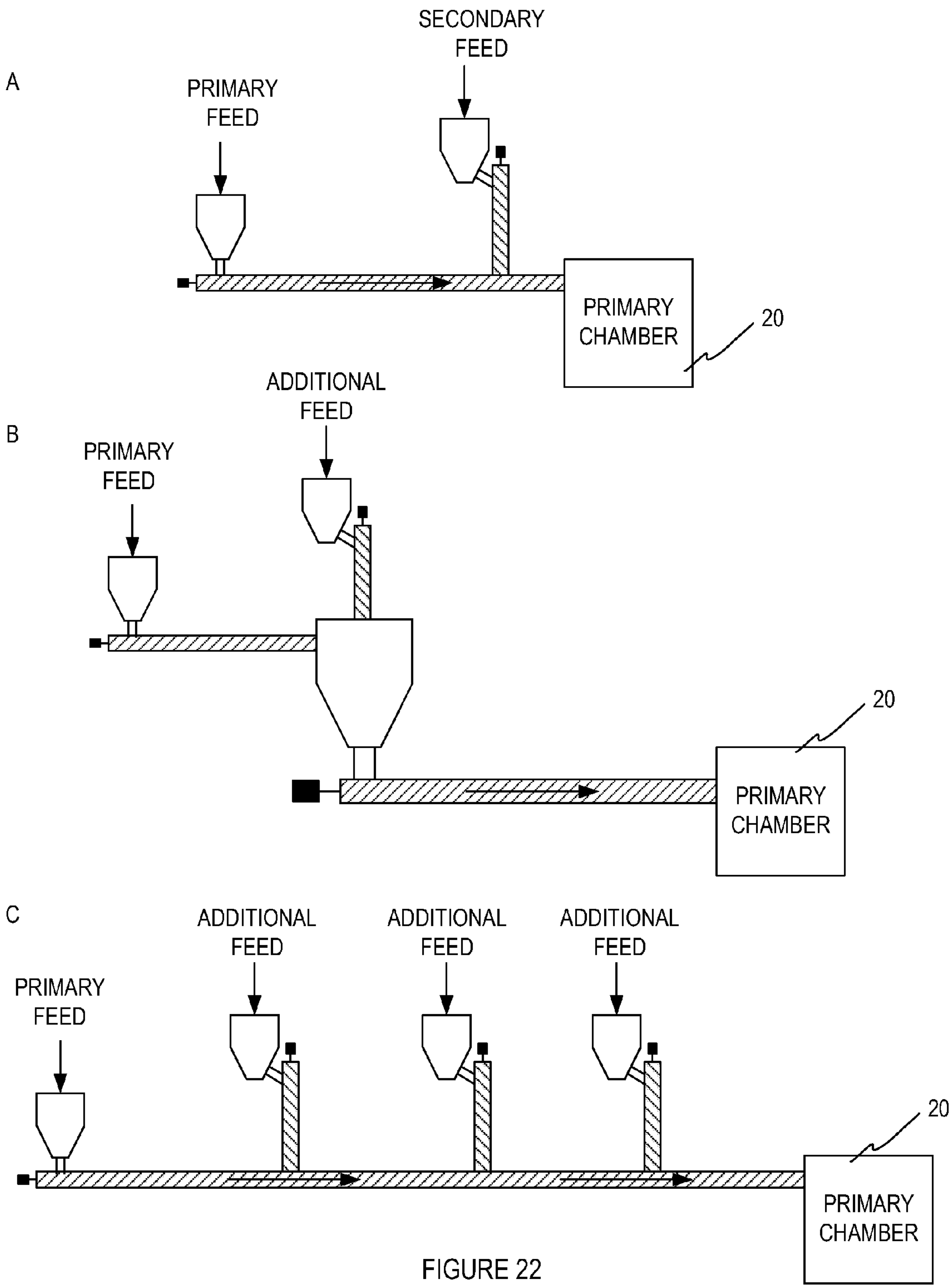

A
PRIMARY FEED
SECONDARY FEED
PRIMARY CHAMBER
20
B
PRIMARY FEED
ADDITIONAL FEED
20
PRIMARY CHAMBER
C
PRIMARY FEED
ADDITIONAL FEED
ADDITIONAL FEED
ADDITIONAL FEED
20
PRIMARY CHAMBER

FIGURE 22

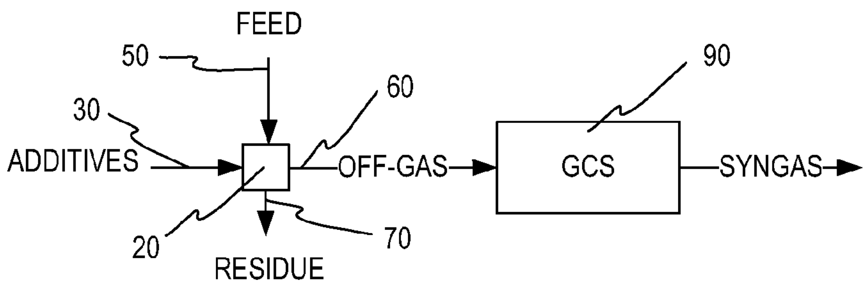


FIGURE 23A

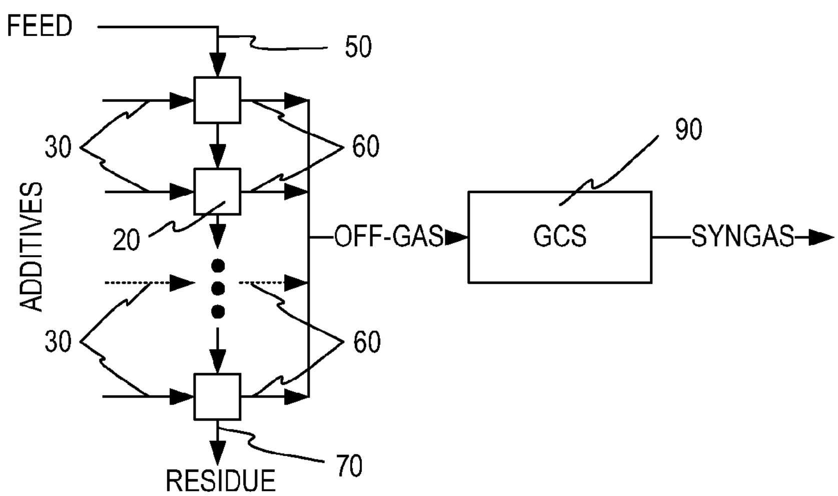


FIGURE 23B

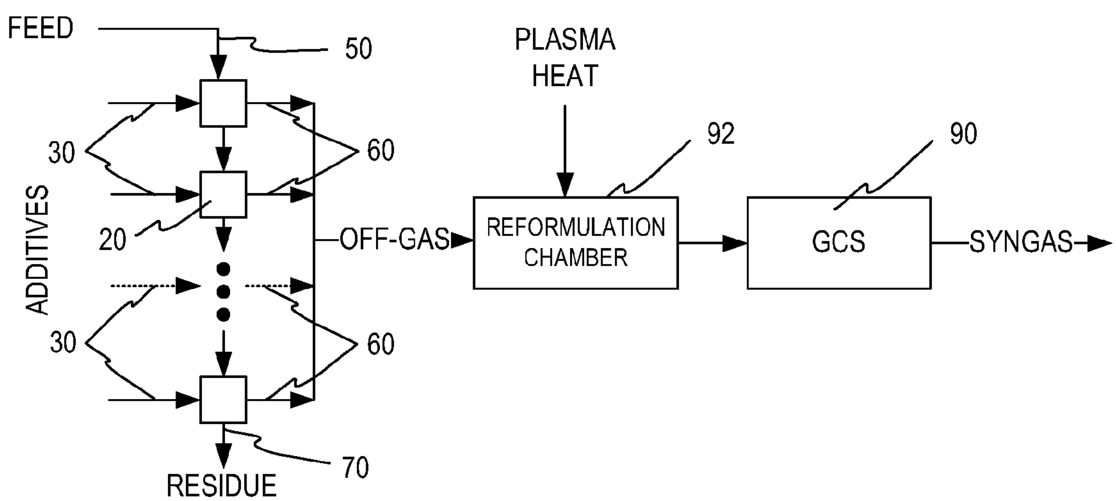


FIGURE 23C

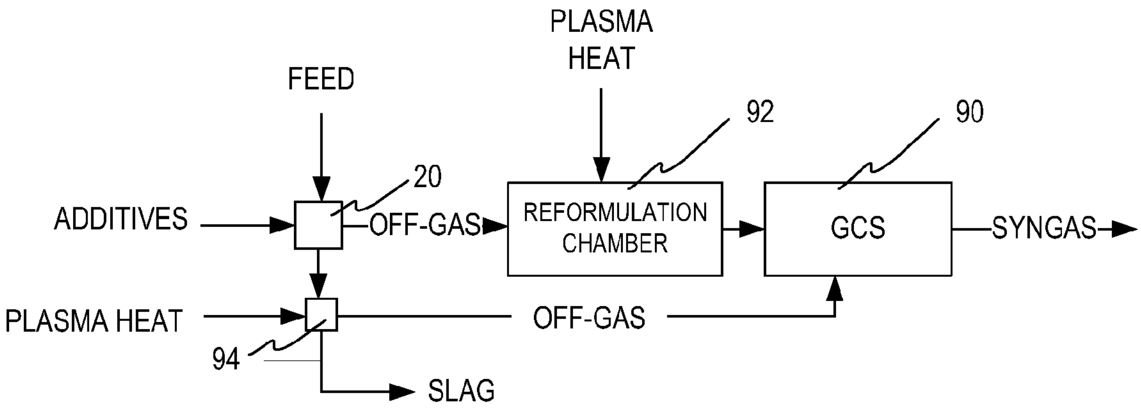


FIGURE 24A

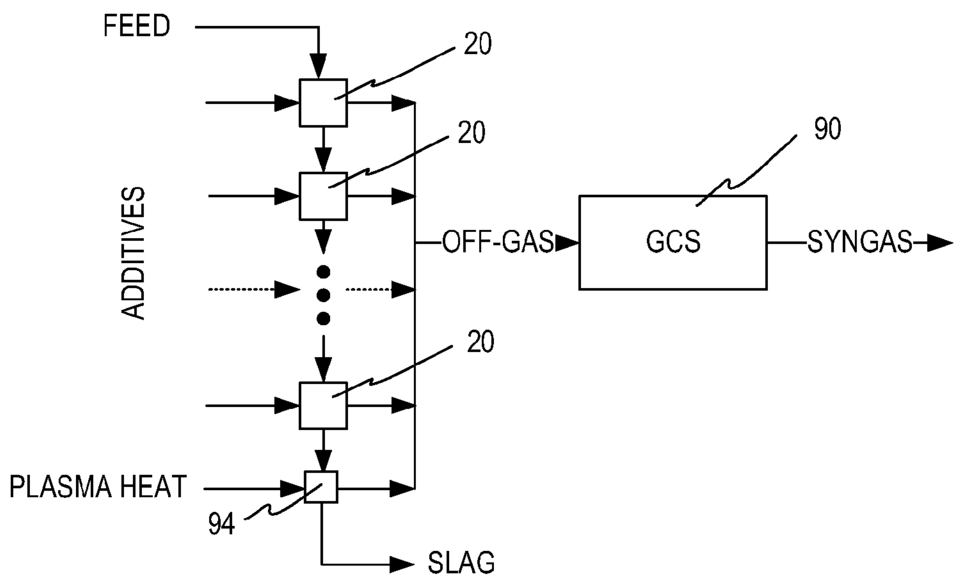


FIGURE 24B

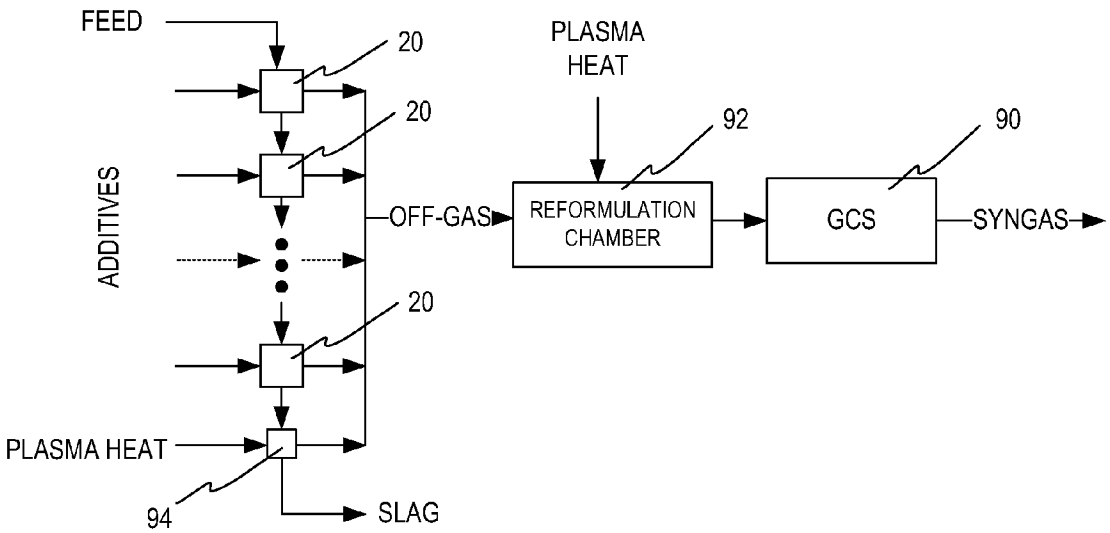


FIGURE 25A

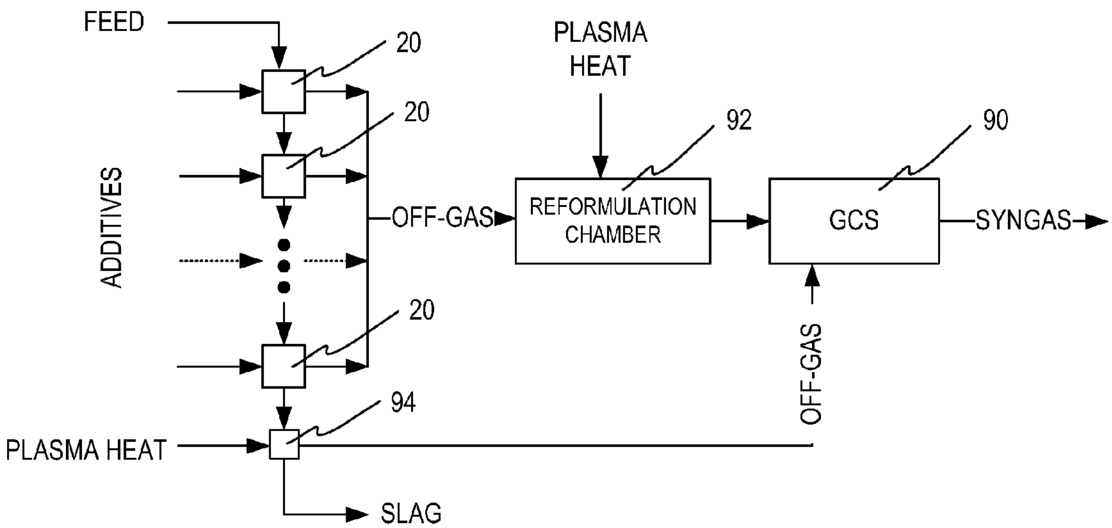


FIGURE 25B

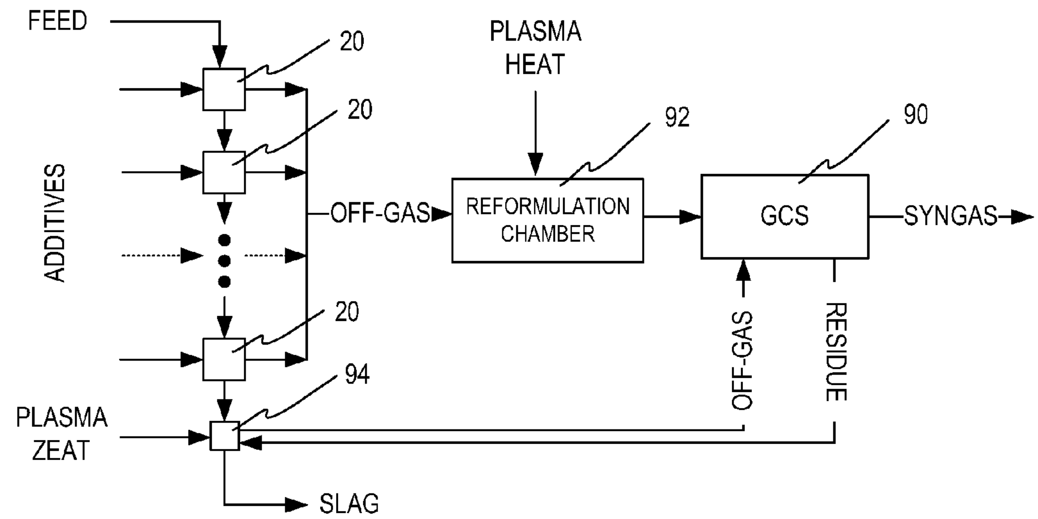


FIGURE 26A

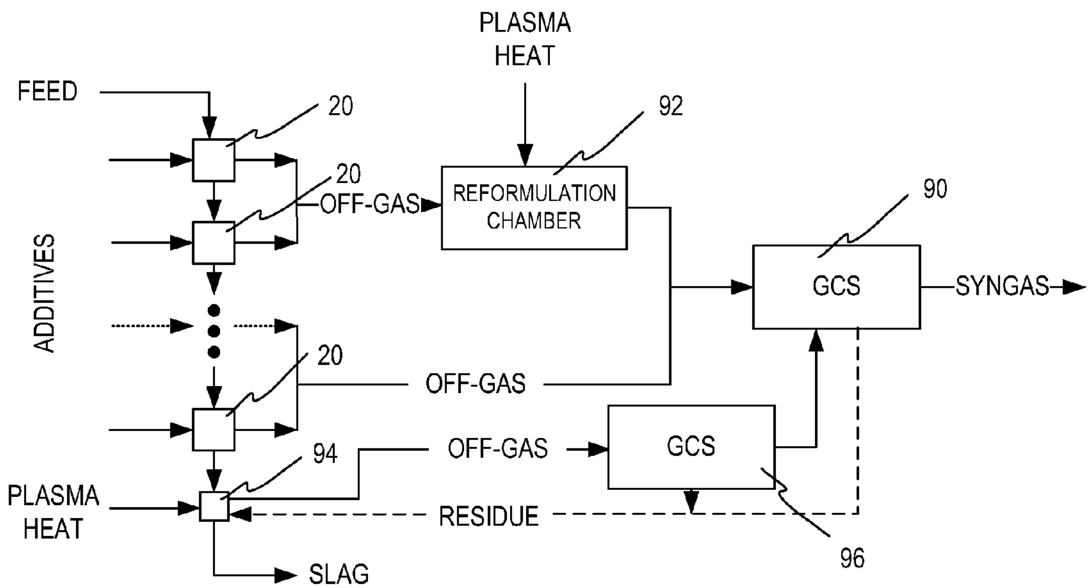


FIGURE 26B

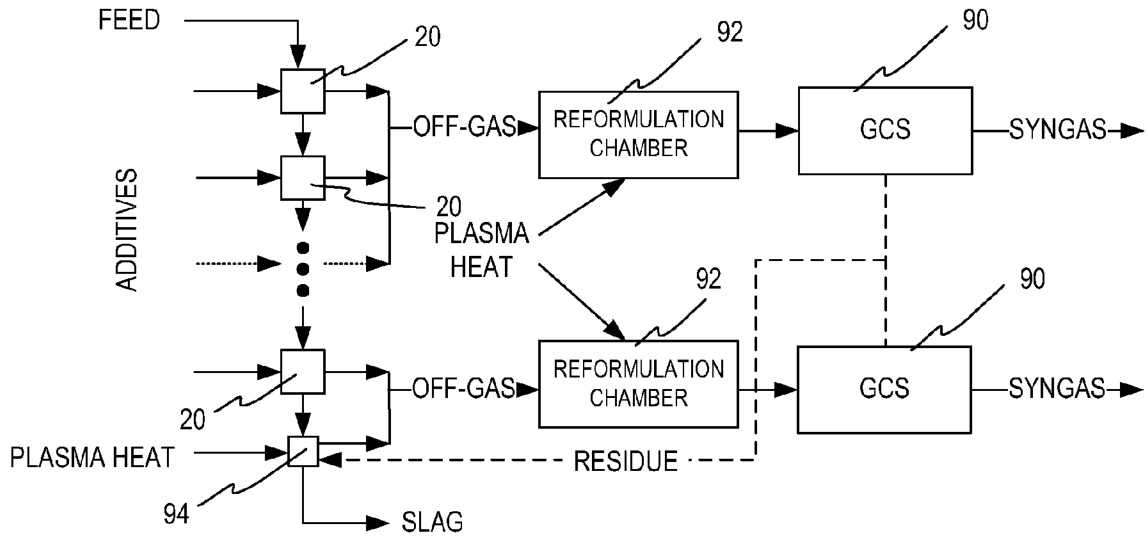

FEED
20
92
90
ADDITIVES
OFF-GAS
REFORMULATION CHAMBER
GCS
SYNGAS
20
PLASMA HEAT
92
90
20
OFF-GAS
REFORMULATION CHAMBER
GCS
SYNGAS
PLASMA HEAT
RESIDUE
94
SLAG

FIGURE 27

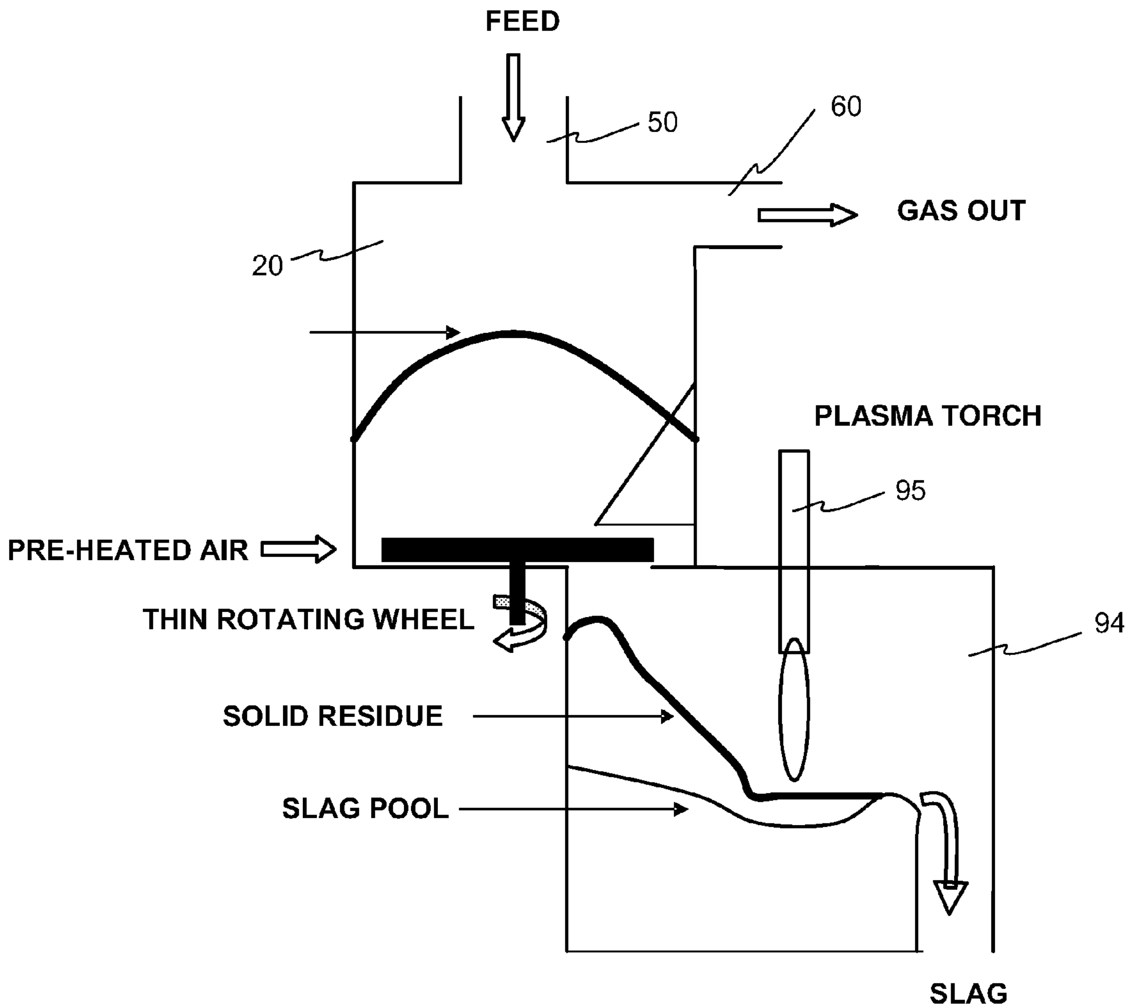

FEED
50
60
GAS OUT
20
PLASMA TORCH
95
PRE-HEATED AIR
94
THIN ROTATING WHEEL
SOLID RESIDUE
SLAG POOL
SLAG

FIGURE 28

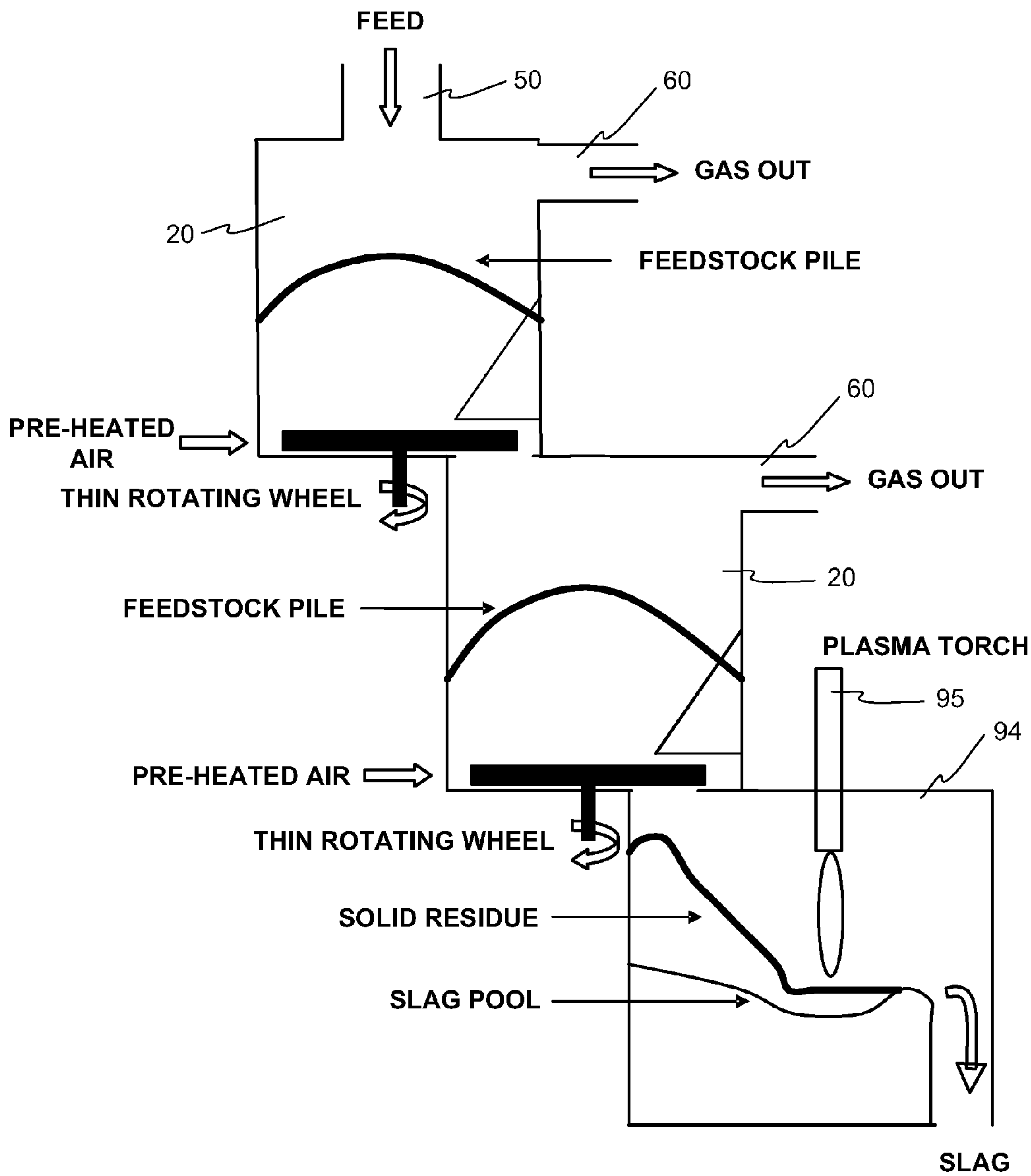

FEED
50
60
GAS OUT
20
FEEDSTOCK PILE
60
PRE-HEATED AIR
GAS OUT
THIN ROTATING WHEEL
20
FEEDSTOCK PILE
PLASMA TORCH
95
94
PRE-HEATED AIR
THIN ROTATING WHEEL
SOLID RESIDUE
SLAG POOL
SLAG

FIGURE 29

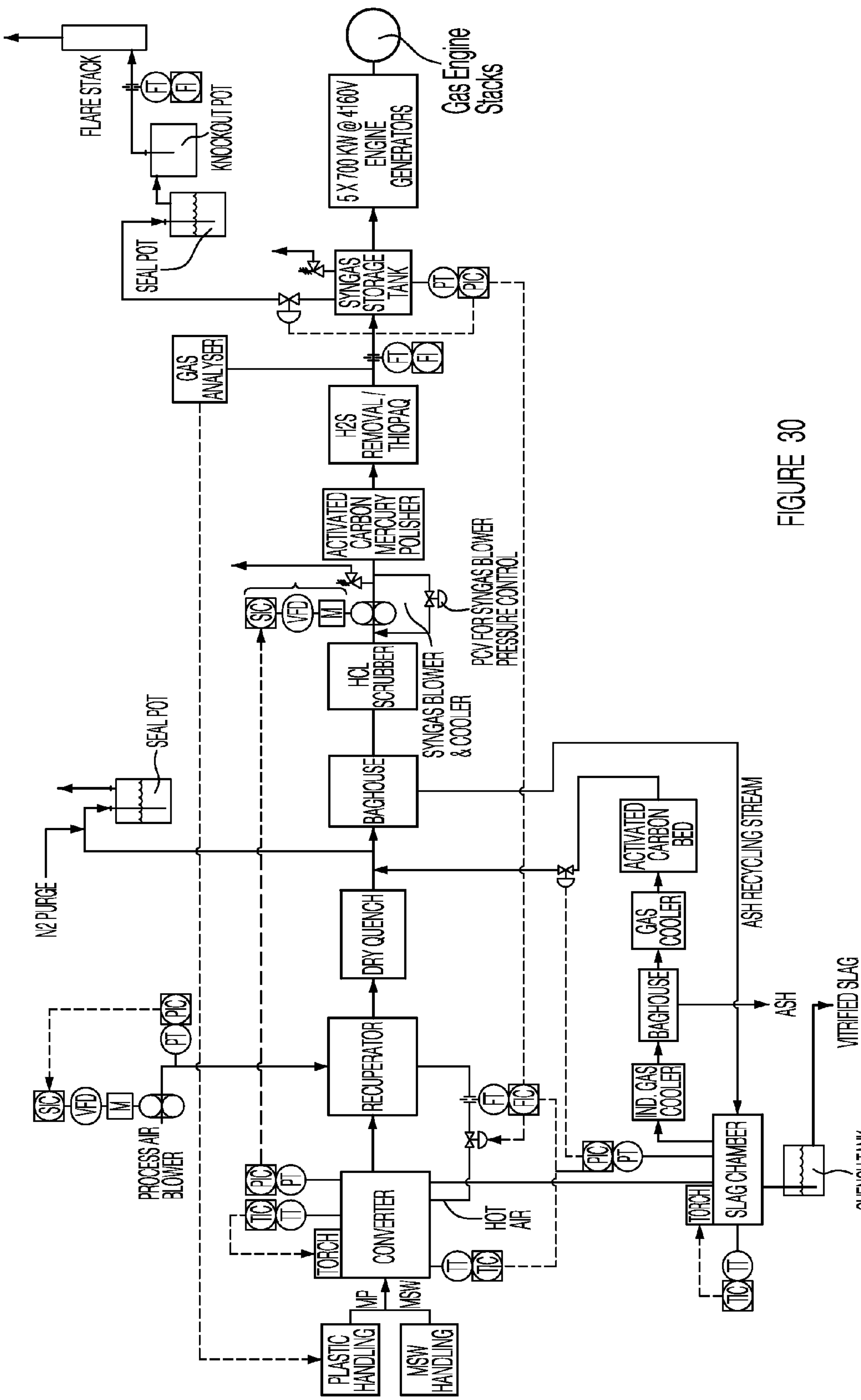

FLARE STACK
FT
FI
KNOCKOUT POT
SEAL POT
5 X 700 KW @ 4160V ENGINE GENERATORS
Gas Engine Stacks
SYNGAS STORAGE TANK
PT
PIC
GAS ANALYSER
FT
FI
H2S REMOVAL / THIOPAQ
ACTIVATED CARBON MERCURY POLISHER
SIC
VFD
M
PCV FOR SYNGAS BLOWER PRESSURE CONTROL
HCL SCRUBBER
SYNGAS BLOWER & COOLER
SEAL POT
BAGHOUSE
ASH RECYCLING STREAM
ACTIVATED CARBON BED
N2 PURGE
DRY QUENCH
GAS COOLER
BAGHOUSE
ASH
VITRIFIED SLAG
SIC
VFD
M
PT
PIC
PROCESS AIR BLOWER
RECUPERATOR
FT
FIC
IND. GAS COOLER
PIC
PT
PIC
PT
TIC
TT
TORCH
CONVERTER
HOT AIR
TT
TIC
TORCH
SLAG CHAMBER
QUENCH TANK
TT
TIC
MP
MSW
PLASTIC HANDLING
MSW HANDLING

FIGURE 30

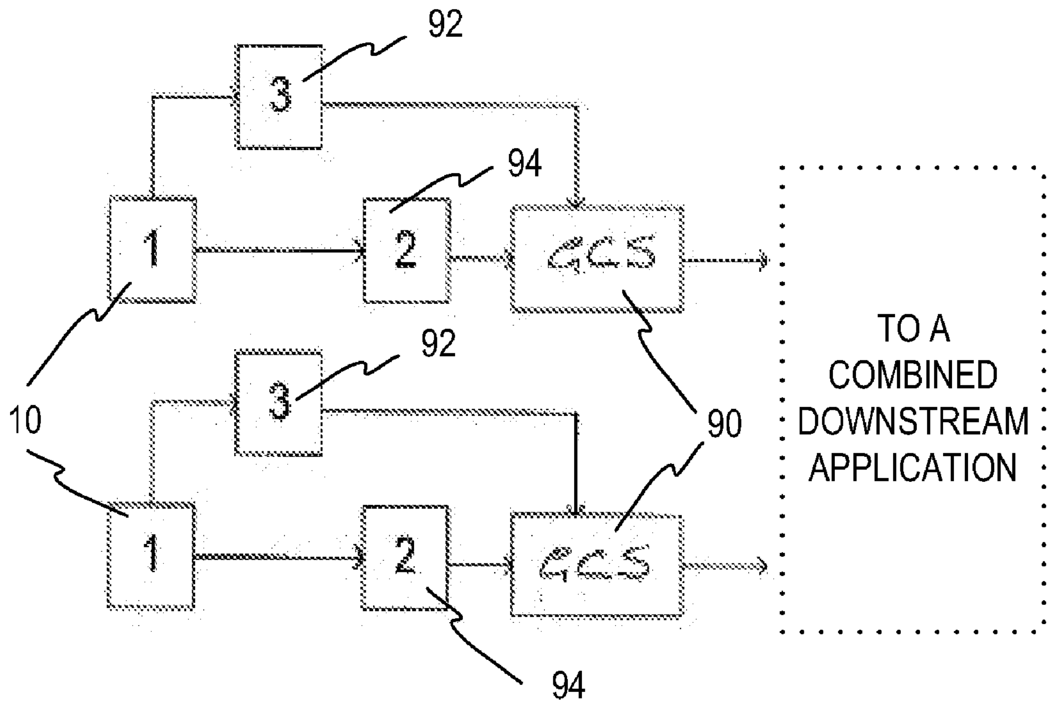

92
3
94
1
2
GCS
92
3
10
1
2
GCS
90
94
TO A
COMBINED
DOWNSTREAM
APPLICATION

FIGURE 31

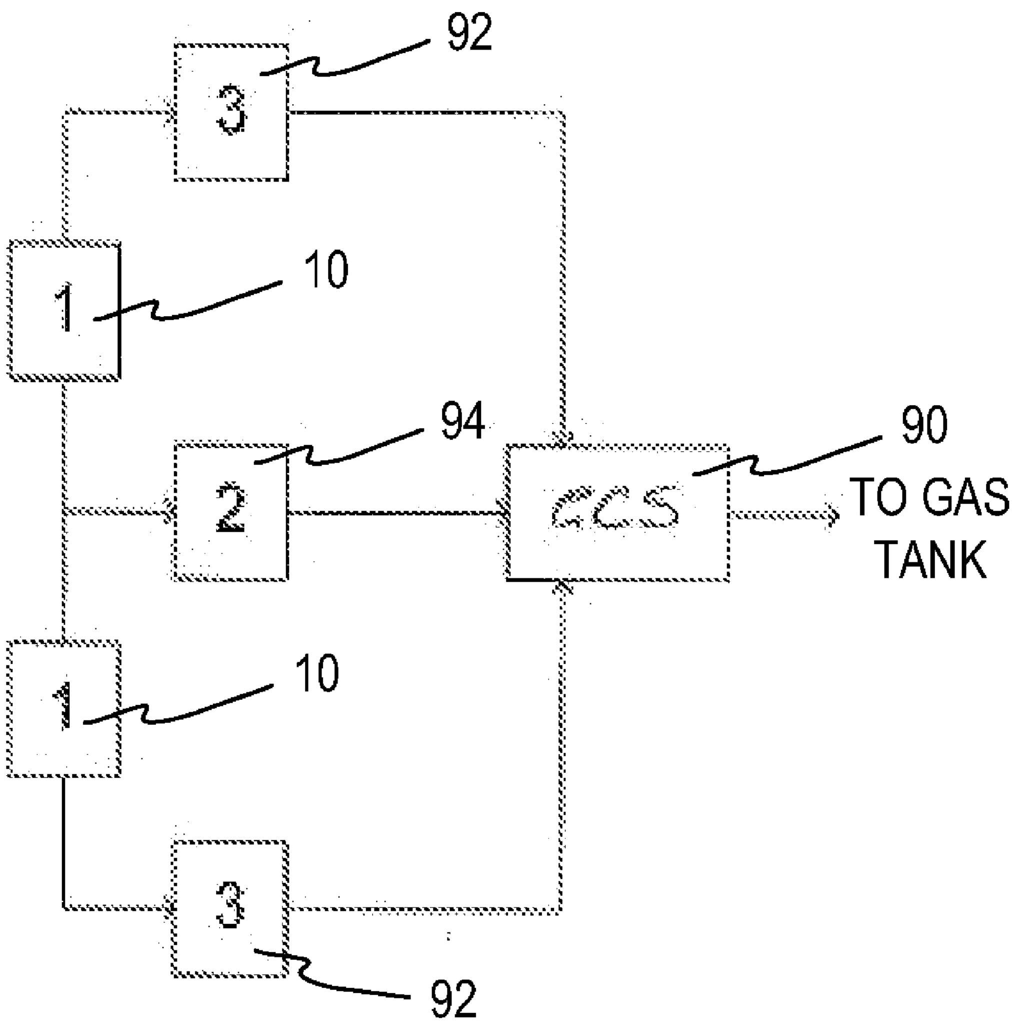


FIGURE 32

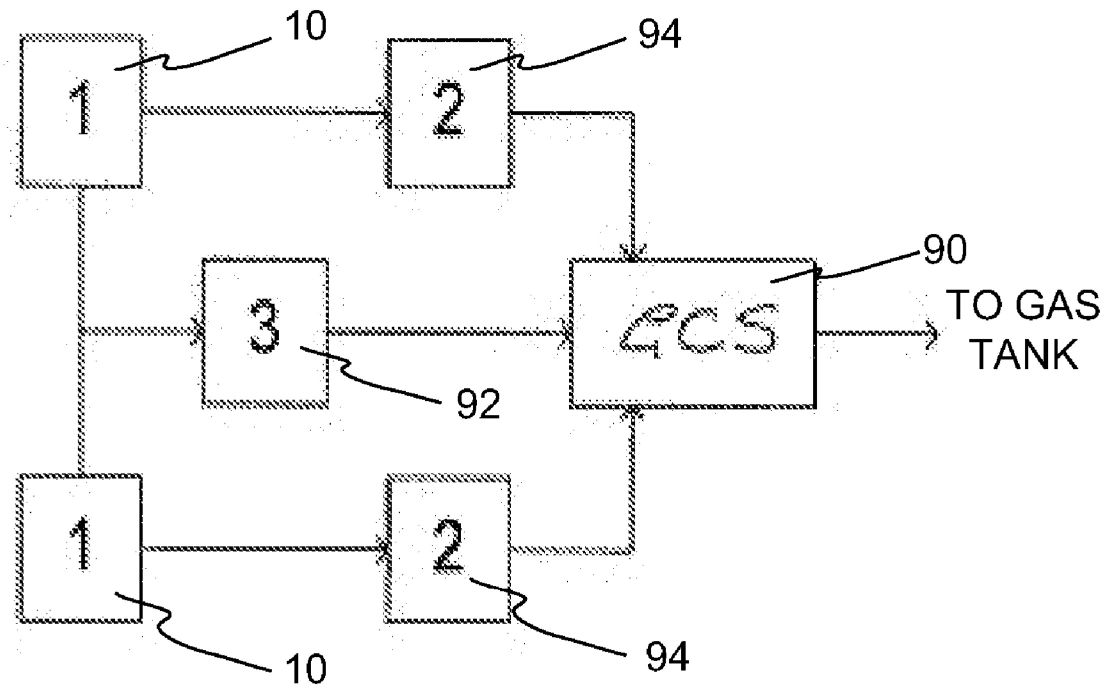


FIGURE 33

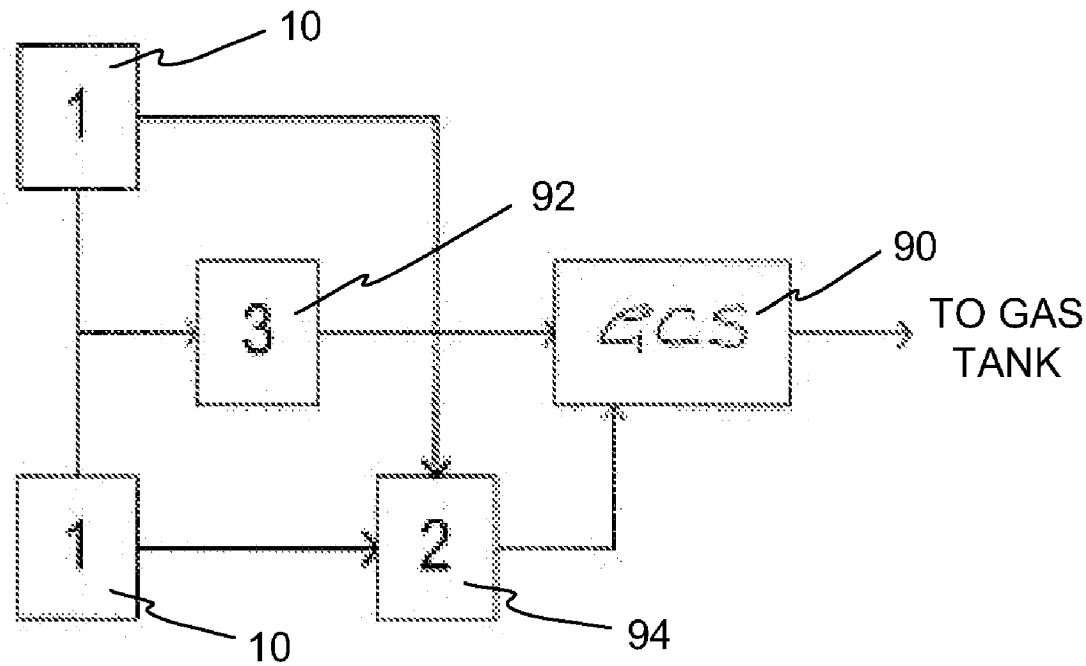


FIGURE 34

GASIFIER COMPRISING VERTICALLY SUCCESSIVE PROCESSING REGIONS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation-in-part and claims benefit of priority to International Patent Application No. PCT/CA000881, filed Jun. 5, 2006. The contents of the aforementioned application is hereby expressly incorporated by reference in its entirety and for all purposes.

FIELD OF THE INVENTION

[0002] The invention pertains to the field of gasification, and, in particular, to a vertically oriented gasifier for conversion of carbonaceous feedstock into a gas.

BACKGROUND

[0003] Gasification is a process that enables the conversion of carbonaceous feedstock, such as municipal solid waste (MSW), biomass or coal, into a combustible product gas. The product gas can be used to generate electricity or as a basic raw material to produce chemicals and liquid fuels.

[0004] Generally, the gasification reaction consists of feeding carbonaceous feedstock into a heated gasifier along with a controlled and/or limited amount of oxygen/air and optionally steam. In contrast to incineration or combustion, which operates with excess oxygen to produce CO_2, H_2O, SOx, and NOx, gasification reactions produce a raw gas composition comprising CO, H_2, H_2S, and NH_3. After clean-up and appropriate processing, the primary gasification products of interest are H_2 and CO.

[0005] Possible uses for the product gas from the gasification reaction 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 fertilisers; the extraction of both hydrogen and carbon monoxide as discrete industrial fuel gases; and other industrial applications.

[0006] A number of systems have been proposed for capturing heat produced by the gasification reaction and utilising such heat to generate electricity, generally known as combined cycle systems. The energy in the product gas coupled with substantial amounts of recoverable sensible heat produced by the process throughout the gasification system can generally produce sufficient electricity to drive the process, thereby alleviating the expense of local electricity consumption.

[0007] 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_2O, H_2, N_2, O_2, CO_2, CO, CH_4, H_2S, NH_3, C_2H_6, unsaturated hydrocarbons such as acetylenes, olefins, aromatics, tars, hydrocarbon liquids (oils) and char (carbon black and ash).

[0008] The means of accomplishing a gasification reaction vary in many ways, but rely on four key engineering factors: the atmosphere (level of oxygen or air or steam content) in the gasifier; the configuration and dimensions of the gasifier; the internal and external heating means; and the operating temperature for the process. Factors that affect the quality of the product gas include: feedstock composition, preparation and particle size; gasifier heating rate; residence time; material feeding method (dry or slurry feed system), the feedstock-reactant flow arrangement, the design of the dry ash or slag removal system; whether it uses a direct or indirect heat generation and displacement method; and the syngas cleanup system. Gasification is usually carried out at a temperature in the range of about 650° C. to 1200° C., either under vacuum, at atmospheric pressure or at pressures up to about 100 atmospheres.

[0009] As the feedstock is heated, water is the first constituent to evolve. As the temperature of the dry feedstock increases, volatilization takes place. During volatilization, the feedstock is thermally decomposed to release tars and light volatile hydrocarbon gases, with the formation of char, a residual solid consisting of both organic and inorganic materials. At high temperatures (such as above 1200° C.), inorganic mineral matter is fused or vitrified to form a molten glass-like substance called slag. The slag 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.

[0010] If the gas generated in the gasification reaction comprises a wide variety of volatiles, such as the kind of gas that tends to be generated in a low temperature gasifier with a "low quality" carbonaceous feedstock, it is generally referred to as off-gas. If the characteristics of the feedstock and the conditions in the gasifier generate a gas in which CO and H_2 are the predominant chemical species, the gas is referred to as syngas. Optionally, the raw off-gas or the raw syngas is converted to a more refined gas composition in a gas reformulating system (GRS) prior to cooling and cleaning through a gas conditioning system (GCS).

[0011] The GRS can employ plasma heat to reformulate the offgas/syngas by converting, reconstituting, or reforming longer chain volatiles and tars into smaller molecules with or without the addition of other inputs or reactants. When gaseous molecules come into contact with the plasma heat, they disassociate into their constituent atoms. Many of these atoms will react with other input molecules to form new molecules, while others may recombine with like atoms (e.g. one hydrogen atom combines with another hydrogen atom). As the temperature of the molecules in contact with the plasma heat decreases, all atoms fully recombine. As input gases can be controlled stoichiometrically, output gases can be controlled to, for example, produce substantial levels of carbon monoxide and insubstantial levels of carbon dioxide. Alternatively, plasma heating can be used within the gasification reaction itself.

[0012] Plasma is a high temperature luminous gas that is at least partially ionised, and is made up of gas atoms, gas ions, and electrons. Plasma can be produced with any gas in this manner. This gives excellent control over chemical reactions in the plasma as the gas might be neutral (for example, argon, helium, neon), reductive (for example, hydrogen, methane, ammonia, carbon monoxide), or oxidative (for example, oxygen, carbon dioxide). In the bulk phase, plasma is electrically neutral.

[0013] The reformulated gas from the GRS may contain small amounts of unwanted compounds and requires further treatment to convert it into a useable product. Undesirable substances such as metals, sulphur compounds and ash may need to be removed from the gas. This is usually done in the gas conditioning system (GCS). For example, dry filtration systems and wet scrubbers are often used in a GCS to remove particulate matter and acid gases from the gas.

[0014] These factors have been taken into account in the design of various different systems which are described, for example, in U.S. Pat. Nos. 6,686,556, 6,630,113, 6,380,507; 6,215,678, 5,666,891, 5,798,497, 5,756,957, and U.S. Patent Application Nos. 2004/0251241, 2002/0144981. There are also a number of patents relating to different technologies for the gasification of coal for the production of synthesis gases for use in various applications, including U.S. Pat. Nos. 4,141,694; 4,181,504; 4,208,191; 4,410,336; 4,472,172; 4,606,799; 5,331,906; 5,486,269, and 6,200,430.

[0015] Numerous converters are known in the art, however, a practical efficient system has not yet achieved significant commercial use. Most of them have been affected in the volatilization stage by heat transfer problems attendant to the large variance in composition and moisture content of the feedstock. To achieve relatively steady state operation, volatilization temperatures must be used that approach the temperature at which slagging of inorganic material occurs within the gasifier. However, in practise, the temperature in the gasifier often rises above the slagging temperature due to variances in content and moisture of the feedstock. This results in formation of a tenaciously adhering slag coating comprising of the inorganic components of the waste melt, on all surfaces of the gasifier exposed to the waste.

[0016] Known vertically oriented gasifiers have utilized fixed-bed processing chambers and moving bed processing chambers, the latter being superior due to their ability to handle the residue without vitrification, and include gravity-induced vertical processing chambers, mechanically-assisted flow processing chambers, entrained flow processing chambers, fluidised bed processing chambers and any combination thereof. All known designs have the direction of flow of input air counter-current to the direction of flow of the reactant material.

[0017] Prior systems and processes in vertically oriented gasifiers have not adequately addressed the problems that must be dealt with on a continuously changing basis. Accordingly, it would be a significant advancement in the art to provide a system that can efficiently gasify carbonaceous feedstock in a manner that maximizes the overall efficiency of the process, and/or the steps comprising the overall process.

[0018] This background information is provided for the purpose of making known information believed by the applicant to be of possible relevance to the invention. No admission is necessarily intended, nor should be construed, that any of the preceding information constitutes prior art against the invention.

SUMMARY OF THE INVENTION

[0019] The object of the invention is to provide a vertically oriented gasifier for conversion of carbonaceous feedstock into a gas.

[0020] In accordance with one aspect of the invention, there is provided a gasifier for conversion of carbonaceous feedstock into gas and residue, the gasifier comprising: one or more processing chambers, two or more vertically successive processing regions being distributed within said one or more processing chambers, within each one of which a respective process selected from the group consisting of drying, volatilization and carbon conversion is at least partially favoured, said processing regions being identified by temperature ranges respectively enabling each said respective process; one or more additive input elements associated with said processing regions for inputting additives to promote each said at least partially favoured process therein; one or more material displacement control modules adapted to control a vertical movement of the feedstock through said processing regions to enhance each said at least partially favoured process; one or more feedstock inputs located near a first of said processing regions; one or more gas outputs; and one or more residue outputs.

[0021] In accordance with another aspect of the invention, there is a provided a vertically oriented gasifier for conversion of carbonaceous feedstock into gas and residue, the gasifier comprising: one or more processing chambers, each one of which comprising one or more additive input elements for input of additives therein, wherein combination of said one or more processing chambers and a positioning of said one or more additive input elements thereof promoting creation of two or more vertically successive processing regions within the gasifier within each one of which a respective process is at least partially favoured, said processing regions being identified by temperature ranges respectively enabling each said respective process; one or more feedstock inputs proximal to a first of said processing regions; one or more material displacement control modules adapted to control a vertical movement of the feedstock through said processing regions to enhance each said at least partially favoured process; one or more gas outputs; and one or more residue outputs.

[0022] In accordance with another aspect of the invention, there is a provided a method for converting a carbonaceous feedstock into gas and residue comprising the steps of: providing a gasifier; creating two or more vertically successive processing regions within said gasifier, within each one of which a respective process selected from the group consisting of drying, volatilization and carbon conversion is at least partially favoured, said processing regions being identified by temperature ranges respectively enabling each said respective process; inputting additives within the gasifier to promote each said at least partially favoured process; controlling a downward movement of the feedstock through said processing regions thereby optimizing each said at least partially favoured process; and outputting the gas and residue from the gasifier.

BRIEF DESCRIPTION OF THE FIGURES

[0023] FIG. **1** shows a general schematic of a vertically oriented gasifier, in accordance with one embodiment of the present invention.

[0024] FIG. **2** shows a general schematic of a vertically oriented gasifier, in accordance with another embodiment of the present invention.

[0025] FIG. **3** shows a general schematic of a vertically oriented gasifier comprising multiple processing chambers with vertically successive movement of the reactant material from one chamber to the next, each with its own set of one or more additives and off-gas extraction points, in accordance with one embodiment of the present invention.

[0026] FIG. **4** is a representation of the processing regions in a gasifier comprising a single processing chamber with symmetric placement of the additive input elements, in accordance with one embodiment of the present invention.

[0027] FIG. **5** is a representation of the processing regions in a gasifier comprising a single processing chamber with asymmetric placement of the additive input elements, in accordance with one embodiment of the present invention.

[0028] FIG. **6** is a representation of the processing regions in an ideal gasifier comprising three processing chambers, each with symmetric placement of the additive input elements to enable the formation of individual processing regions for drying, volatilization and carbon conversion, in accordance with one embodiment of the present invention.

[0029] FIG. **7** is a representation of the processing regions in a gasifier comprising three processing chambers, each with symmetric placement of the additive input elements enabling the formation of processing regions with different proportion of the drying, volatilization and carbon conversion processes occurring in them, in accordance with one embodiment of the present invention.

[0030] FIG. **8** is a representation of the processing regions in a gasifier with two processing chambers, with the first processing chamber containing the drying and volatilization regions and the second processing chamber predominantly containing the carbon conversion region, in accordance with one embodiment of the present invention.

[0031] FIG. **9** is a representation of the processing regions in a gasifier with two processing chambers, with the first processing chamber containing the drying region predominantly and the second processing chamber containing the volatilization and carbon conversion region, in accordance with one embodiment of the present invention.

[0032] FIG. **10** shows the schematic of a gasification system with a gasifier with a lateral material displacement control module followed by a gasifier with vertical material displacement control module, in accordance with one embodiment of the present invention.

[0033] FIG. **11** shows the schematic of a gasification system with a gasifier with a vertical material displacement control module followed by a gasifier with lateral material displacement control module, in accordance with one embodiment of the present invention.

[0034] FIG. **12** is a cross-sectional schematic diagram of a processing chamber with a rotating arm-based material displacement control module, in accordance with one embodiment of the invention. FIG. **12**B is the top-view of the rotating arm-based material displacement control module.

[0035] FIG. **13**A is a perspective, cut away view of a processing chamber using an extractor screw-based material displacement control module, in accordance with an embodiment of the invention. FIG. **13**B shows a cross-sectional view of a slight variation where the residue outlet is moved away from the main processing chamber to avoid direct drop, in accordance with one embodiment of the present invention.

[0036] FIG. **14**A is a perspective, cut away view of a processing chamber using a pusher ram-based material displacement control module, in accordance with one embodiment of the invention. FIGS. **14**B and **14**C show cross-sectional views of two different processing chambers using pusher ram-based material displacement control modules, in accordance with one embodiment of the present invention.

[0037] FIGS. **15**A and **15**B show embodiments of rotating grates that can be used in a material displacement control module, in accordance with different embodiments of the present invention.

[0038] FIGS. **16**A and **16**B show various embodiments for movement of reactant material from one processing chamber to another in a two-processing chamber gasifier. The material displacement control modules employed include (a) gravity; (b) gravity with sideways top valve; (c) gravity with hopper; (d) gravity with screw; (e) vertical screw; (f) horizontal extractor screw; (g) vertical screw with hopper; (h) gravity with screw and hopper; and (i) horizontal extractor screw and hopper.

[0039] FIG. **17** is a schematic diagram of an entrained flow processing chamber, in accordance with one embodiment of the invention, in accordance with one embodiment of the present invention.

[0040] FIG. **18** is a schematic diagram of an fluidized bed processing chamber, in accordance with one embodiment of the invention, in accordance with one embodiment of the present invention.

[0041] FIG. **19** is a schematic diagram of a moving bed processing chamber, in accordance with one embodiment of the invention, in accordance with one embodiment of the present invention.

[0042] FIGS. **20**A to **20**D show different embodiments for the placement of additive input elements around the processing chamber with the depiction of the processing regions in each case, in accordance with one embodiment of the present invention.

[0043] FIGS. **21**A and **21**B show different shapes of processing chambers according to different embodiments of the invention, in accordance with one embodiment of the present invention.

[0044] FIG. **22** shows different embodiments of feedstock input means to the gasifier: (a) secondary feed fed to the primary feed screw; (b) primary and secondary feed fed into a mixed hopper and conveyed via screw to the gasifier; and (c) for two or more feed streams.

[0045] FIGS. **23**A, **23**B and **23**C show the connection of a single-chamber or multi-chamber vertically oriented gasifier to a gas conditioning system (GCS) either through or without a gas reformulating system (GRS), in accordance with one embodiment of the present invention.

[0046] FIGS. **24**A and **24**B show a system similar to that of FIG. **23**, further connected to a residue conditioning system, in accordance with one embodiment of the present invention.

[0047] FIGS. **25**A and **25**B show a system similar to that of FIGS. **23** and **24**, with further transfer of product gas from the residue conditioning system either to the GRS or to the GCS.

[0048] FIG. **26**A shows the use of a GCS for the product gas generated in a residue conditioning system, in accordance with one embodiment of the present invention.

[0049] FIG. **26**B shows the use of a mini-GCS for the product gas generated in a residue conditioning system before it is fed to a primary GCS, in accordance with one embodiment of the present invention.

[0050] FIG. **27** shows a modular approach for building a gasification facility comprising of two parallel streams with independent GRS and GCS.

[0051] FIG. **28** is a cross-sectional schematic of a cascade of a gasifier with a single processing chamber with a plasma-based residue conditioning system.

[0052] FIG. **29** is a cross-sectional schematic of a cascade of a gasifier with two processing chambers with a plasma-based residue conditioning system.

[0053] FIG. **30** shows one embodiment of a distributed control system for a gasification facility using a gasifier, GRS, GCS, GHS and a downstream application for the output syngas generated upstream.

[0054] FIGS. **31** to **34** depict various combinations of how the different function blocks processes of a gasification facility can be constructed, wherein "1" depicts function block **1** (a gasifier), "2" depicts a function block **2** (a residue conditioning system) and "3" depicts function block **3** (a gas reformulating system).

DETAILED DESCRIPTION OF THE INVENTION

Definitions

[0055] As used herein, the term 'about' refers to a +/−10% variation from the nominal value. It is to be understood that such a variation is always included in any given value provided herein, whether or not it is specifically referred to.

[0056] The terms 'carbonaceous feedstock' and 'feedstock', as used interchangeably herein, are defined to refer to carbonaceous material that can be used in the gasification process. Examples of suitable feedstock include, but are not limited to, hazardous and non-hazardous waste materials, including municipal wastes; wastes produced by industrial activity; biomedical wastes; carbonaceous material inappropriate for recycling, including non-recyclable plastics; sewage sludge; coal; heavy oils; petroleum coke; heavy refinery residuals; refinery wastes; hydrocarbon contaminated solids; biomass; agricultural wastes; municipal solid waste; hazardous waste and industrial waste. Examples of biomass useful for gasification include, but are not limited to, waste wood; fresh wood; remains from fruit, vegetable and grain processing; paper mill residues; straw; grass, and manure.

[0057] The term 'reactant material' is defined to refer to any feedstock, including but not limited to partially or fully processed feedstock.

[0058] As used herein, the term, 'input' denotes that which is about to enter or be communicated to any system or component thereof, is currently entering or being communicated to any system or component thereof, or has previously entered or been communicated to any system or component thereof. An input includes, but is not limited to, compositions of matter, information, data, and signals, or any combination thereof. In respect of a composition of matter, an input may include, but is not limited to, influent(s), reactant(s), reagent(s), fuel(s), object(s) or any combinations thereof. In respect of information, an input may include, but is not limited to, specifications and operating parameters of a system. In respect of data, an input may include, but is not limited to, result(s), measurement(s), observation(s), description(s), statistic(s), or any combination thereof generated or collected from a system. In respect of a signal, an input may include, but is not limited to, pneumatic, electrical, audio, light (visual and non-visual), mechanical or any combination thereof. An input may be defined in terms of the system, or component thereof, to which it is about to enter or be communicated to, is currently entering or being communicated to, or has previously entered or been communicated to, such that an input for a given system or component of a system may also be an output in respect of another system or component of a system. Input can also denote the action or process of entering or communicating with a system.

[0059] As used herein, the term 'output' denotes that which is about to exit or be communicated from any system or component thereof, is currently exiting or being communicated from any system or component thereof, or has previously exited or been communicated from any system or component thereof. An output includes, but is not limited to, compositions of matter, information, data, and signals, or any combination thereof. In respect of a composition of matter, an output may include, but is not limited to, effluent(s), reaction product(s), process waste(s), fuel(s), object(s) or any combinations thereof. In respect of information, an output may include, but is not limited to, specifications and operating parameters of a system. In respect of data, an output may include, but is not limited to, result(s), measurement(s), observation(s), description(s), statistic(s), or any combination thereof generated or collected from a system. In respect of a signal, an output may include, but is not limited to, pneumatic, electrical, audio, light (visual and non-visual), mechanical or any combination thereof. An output may be defined in terms of the system, or component thereof, to which it is about to exit or be communicated from, currently exiting or being communicated from, or has previously exited or been communicated from, such that an output for a given system or component of a system may also be an input in respect of another system or component of a system. Output can also denote the action or process of exiting or communicating with a system.

[0060] The term 'residue' generally refers to the residual material produced during processes for the gasification or incineration of carbonaceous feedstocks. These include the solid and semi-solid by-products of the process. Such a residue generally consists of the inorganic, incombustible materials present in carbonaceous materials, such as silicon, aluminium, iron and calcium oxides, as well as a proportion of unreacted or incompletely converted carbon. As such, the residue may include char, ash, and/or any incompletely converted feedstock passed from the gasification chamber. The residue may also include materials recovered from downstream gas conditioning processes, for example, solids collected in a gas filtering step, such as that collected in a baghouse filter. The residue may also include solid products of carbonaceous feedstock incineration processes, which may come in the form of incinerator bottom ash and flyash collected in an incinerator's pollution abatement suite.

[0061] 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 a gasification 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 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 a gasification 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.

[0062] 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 pre-determined, 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 a gasification 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 a gasification 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 a gasification 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 a gasification 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.

[0063] As used herein, the term 'real-time' is used to define any action that is substantially reflective of the present or current status of the system or process, or a characteristic thereof, to which the action relates. A real-time action may include, but is not limited to, a process, an iteration, a measurement, a computation, a response, a reaction, an acquisition of data, an operation of a device in response to acquired data, and other such actions implemented within the system or a given process implemented therein. It will be appreciated that a real-time action related to a relatively slow varying process or characteristic may be implemented within a time frame or period (e.g. second, minute, hour, etc.) that is much longer than another equally real-time action related to a relatively fast varying process or characteristic (e.g. 1 ms, 10 ms, 100 ms, 1 s).

[0064] As used herein the term 'continuous' is used to define any action implemented on a regular basis or at a given rate or frequency. A continuous action may include, but is not limited to, a process, an iteration, a measurement, a computation, a response, a reaction, an acquisition of data via a sensing element, an operation of a device in response to acquired data, and other such actions implemented within the system or in conjunction with a given process implemented therein. It will be appreciated that a continuous action related to a relatively slow varying process or characteristic may be implemented at a rate or frequency (e.g. once/second, once/minute, once/hour, etc.) that is much slower than another equally continuous action related to a relatively fast varying process or characteristic (e.g. 1 KHz, 100 Hz, 10 Hz, 1Hz).

[0065] 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.

[0066] The invention provides a gasifier comprising two or more vertically successive processing regions, within which a certain process such as drying, volatilization or carbon conversion is at least partially favoured. The processing regions are identified by their different temperature ranges that enable the different processes therein. The gasifier comprises one or more processing chambers; the vertically successive processing regions are distributed throughout the one or more processing chambers. Additive input elements are associated with the processing regions to promote the at least partially favoured process therein. Thus, the processing regions can be considered to be promoted by a combination of the one or more processing chambers and/or by a positioning of the one or more additive input elements in each of the processing chambers. The gasifier comprises one or more feedstock inputs located near the first processing region, one or more gas outputs, one or more residue outputs, one or more material displacement control modules and optionally, a global control system.

[0067] In the following discussion, the overall gasification process will be considered to consist of three processes in sequence: drying, volatilization and carbon conversion. It will be appreciated that these processes are meant to be exemplary only and should not be considered to be limited to this example as a gasification process can be defined to consist of any two or more processes, as can any such process can be defined to consist of one or more sub-processes as appropriate. For the purpose of clarity and consistency, the following will focus on describing various embodiments of the present invention wherein the gasification process consists of three exemplary processes described below.

[0068] (a) Drying of the Material

[0069] The feedstock delivered into the gasifier undergoes a drying process under a temperature range between 25° C.

and 200° C. In this temperature range, drying may also be accompanied by minor amounts of volatilization.

[0070] (b) Volatilization of the Material

[0071] This process occurs mainly between 350° C. and 800° C. and may also be accompanied by a small remainder of the drying operation as well as a substantial amount of carbon conversion. The composition of air supplied in this region is typically varied depending on the feedstock supplied (e.g. oxygen enriched or depleted air).

[0072] (c) Carbon Conversion

[0073] At temperatures between 900° C. and 1000° C., the main process reaction occurring is that of carbon conversion with the remainder of volatilization. By this time most of the moisture has been removed from the material. The flow rate of air supplied can be varied depending on the reactant material supplied. Steam is also optionally added in this region.

[0074] A worker skilled in the art would readily appreciate that in a given temperature range, all of the three processes are occurring somewhat simultaneously and continuously, though, depending on the temperature range, one of the processes is at least partially favoured.

[0075] In one embodiment of the invention, the gasifier comprises three vertically successive processing regions with the first processing region at least partially favouring drying, the second processing region at least partially favouring volatilization and the third processing region at least partially favouring carbon conversion. A worker skilled in the art will understand that the gasifier can in general comprise of a large number of processing regions with a different proportion of drying, volatilization or carbon conversion occurring in each processing region. Thus, the number of processing regions can be as many or as few as desired, without loss of generality.

[0076] The present invention provides a vertically oriented gasifier for conversion of carbonaceous feedstock into a fuel gas. In general, the gasifier comprises one or more processing chambers, each one of which comprises one or more additive input elements for input of additives therein, wherein combination of the one or more processing chambers and a positioning of the one or more additive input elements, or group thereof, enable two or more vertically successive processing regions within the gasifier, within each one of which a respective process is at least partially favoured. The gasifier further comprises one or more feedstock inputs for input of the feedstock into a first of the processing regions, one or more material displacement control modules for controlling a downward displacement of the feedstock through the processing regions for enhancing each respective process, one or more gas outputs for output of gas from the gasifier, and one or more residue outputs for output of residue from the gasifier.

[0077] For example, with reference to the embodiment of FIG. **1**, a gasifier **10** having a single processing chamber **20** may comprise two or more distinct additive input elements **30**, or groups thereof, positioned so to respectively promote or favour processes within respective vertically successive processing regions **40** within the single processing chamber **20**. A feedstock input **50** provides feedstock to the first of the processing regions **40**, a gas output **60** for output of gas from the gasifier **10**, and a residue output **70** for output of residue from the gasifier **10**. The orientations and positions of the input and output elements for feedstock, additives, residue and gas, in FIG. **1** are merely exemplary and any variations in their orientations and positions are considered to be within the scope and nature of the invention disclosed herein.

[0078] A material displacement control module operatively controlling one or more process devices and/or mechanisms (not shown) configured to control a vertical displacement or a rate of vertical displacement of the material through the vertically successive processing regions, is also provided thereby promoting the efficient processing of the material within each of these processing regions wherein a particular process is at least partially favoured. For example, as will be described in greater detail below, various devices and/or mechanisms may be controlled by the material displacement control module to implement a downward displacement of the material, either by direct control of material displacement between each processing region, by controlled extraction of material from a lowermost processing region thereby indirectly controlling a downward displacement of material from an uppermost processing region toward the lowermost processing region under gravity, or using any combination thereof.

[0079] As depicted by the additives input and off-gas output phantom lines of FIG. **1**, it will be appreciated that additives may be input in each processing region, for instance via appropriate positioning of additive input elements adapted therefor, or provided to a select number of these processing regions as appropriate for a given design and embodiment of the gasifier **10**. It will also be appreciated that the additive input elements may be actively controlled by a common response element configured to provide a pre-selected quantity or input rate of additives (e.g. set absolute or relative input) for a given sensed process characteristic (e.g. process temperature, pressure, throughput, etc.; product gas quality, quantity, composition, pressure, flow, heating value etc.; feedstock input rate, quality, composition, etc; and the like), or again controlled by distinct response elements, possibly operatively linked via a same local, regional and/or global control system.

[0080] Similarly, gas outputs may be provided for each processing region independently, or provided by one or more cooperative gas outputs allowing for the output of off-gases from the processing chamber **20** from more than one processing region simultaneously.

[0081] In the embodiment of FIG. **2**, a gasifier **110** may comprise two or more processing chambers **120** vertically and operatively coupled, each comprising one or more additive input elements **130**, or groups thereof, positioned so to respectively promote or favour processes within respective processing regions **140** of each processing chamber **120**, thereby providing a vertical succession of two or more processing regions **140** when the processing chambers **120** are combined. A feedstock input **150** provides feedstock to the first of the processing regions **140**, a gas output **160** provides for output of gas from the gasifier **110**, and a residue output **170** provides for output of residue from the gasifier **110**. The orientations and positions of the input and output elements for feedstock, additives, residue and gas, in FIG. **2** are merely exemplary and any variations in their orientations and positions are considered to be within the scope and nature of the invention disclosed herein.

[0082] A material displacement control module operatively controlling one or more process devices and/or mechanisms (not shown) configured to control a vertical displacement of the material through the vertically successive processing regions (i.e. between chambers and/or through the processing regions of a same chamber), is also provided thereby promoting the efficient processing of the material within each of these processing regions wherein a particular process is at least partially favoured. For example, as will be described in greater detail below, various devices and/or mechanisms may be controlled by the material displacement control module to implement a downward displacement of the material, either by direct control of material displacement between each processing region, by controlled extraction of material from a lowermost processing region thereby indirectly controlling a downward displacement of material from an uppermost processing region toward the lowermost processing region under gravity, or using any combination thereof.

[0083] As depicted by the additives input solid and phantom lines of FIG. **2**, it will be appreciated that additives will generally be input in each processing chamber, though not exclusively, and may also optionally be input at multiple locations within a given processing chamber to promote definition of two or more processing regions therein. It will also be appreciated that the additive input elements may be actively controlled by a common response element configured to provide a pre-selected quantity or input rate of additives (e.g. set absolute or relative input) for a given sensed process characteristic (e.g. process temperature, pressure, throughput, etc.; product gas quality, quantity, composition, pressure, flow, heating value etc.; feedstock input rate, quality, composition, etc; and the like), or again controlled by distinct response elements, possibly operatively linked via a same local, regional and/or global control system.

[0084] Similarly, off-gas outputs may be provided for each processing chamber independently, or provided by one or more cooperative off-gas outputs allowing for the output of gas form more than one processing chamber **120** at a time.

[0085] As will be described in greater detail with reference to a number of illustrative embodiments of the present invention, various combinations of processing chambers and additive input elements therefor can be adapted to provide two or more vertically successive processing regions as contemplated herein, wherein an appropriate material displacement control module can be adapted for a given embodiment to enable the controlled displacement of material through these processing regions to enhance a processing thereof. Such control may be imparted uniquely for each of the one or more processing chambers of the gasifier, optionally imparting indirect displacement of material through successive processing regions of the same processing chamber within which more than one processing region is defined and/or imparting a displacement of material from a first processing chamber to a subsequent vertically successive processing chamber of a gasifier comprising more than one processing chamber. Alternatively, control may be imparted to various cooperative control devices and/or mechanisms configured to directly control displacement of material from one processing region to another, possibly within a same processing chamber.

[0086] In one embodiment **310**, and referring to FIG. **4**, the symmetrical placement of three sets of additive input elements, or groups thereof **330**, around one processing chamber **320** promotes the substantially horizontally planar nature of the interfaces between the resulting three processing regions **340**.

[0087] In one embodiment **410**, and referring to FIG. **5**, three additive input elements, or groups thereof **430**, are placed asymmetrically around the processing chamber **420** resulting in non-horizontally planar interfaces between the resulting three processing regions **440**.

[0088] It will generally be appreciated that symmetric processing regions may promote optimal gasification and can generally be enhanced using mixing/agitation means (e.g. as seen in FIG. **19**). Such agitation means may comprise, for example, a rotating shaft controlled using a motorized drive. These agitator shafts can also be operated, in one embodiment, as a sensing element of an integrated global control system wherein torque measurements on these shafts can serve as an indicator of the pile height, especially if the agitator has multi-level flights. To reduce false reports due to the formation of agglomeration on the flights, two agitator shafts may be used which clean each other as they rotate, thus knocking off agglomeration. Other such agitators may be considered herein without departing from the general scope and nature of the present disclosure, as will be apparent to the person of skill in the art.

[0089] In one embodiment of the invention, the gasifier comprises two or more processing chambers each one of which comprising one or more additive input elements. Each of the two or more processing chambers provides a different processing region and the different processing chambers are arranged in a vertically successive fashion.

[0090] In one embodiment and referring to FIG. **6**, the gasifier **510** comprises three processing chambers **520** each with its own additive input elements, or groups thereof **530**, positioned as to promote definition of one processing region **540** in each processing chamber **520**, wherein each of the three processes of gasification (drying, volatilization and carbon conversion) is respectively favoured. A worker skilled in the art will readily understand that the scenario in FIG. **6** is ideal and in practice, each processing region however will have different proportion of each of the gasification processes taking place, as shown in FIG. **7**, for example.

[0091] The different processing chambers can also be separately optimized for maximal efficiencies. In one embodiment of the invention, and referring to FIG. **8**, the gasifier **710** comprises two processing chambers **720**, the first one of which is used predominantly for drying and volatilization while the second processing chamber is used predominantly for carbon conversion. In this embodiment, each processing chamber **720** in the gasifier **710** exits its off-gas stream through an outlet **760** which may be kept separated or merged. These off-gas streams may either be sent to a storage tank or for further processing in a gas reformulating system (GRS). In an alternate embodiment, and referring to FIG. **9**, the first processing chamber is used predominantly for drying and the second processing chamber is used predominantly for volatilization and carbon conversion.

[0092] Multiple processing chambers are also useful if the feedstock has a high content of plastics. In this situation, the use of the second processing chamber can be used to recover additional valuable compounds such as paraffins and waxes. This can be accomplished by operating the first processing chamber at a lower temperature than the second processing chamber.

[0093] A worker skilled in the art will understand that while we have described a vertically oriented gasifier as taking in carbonaceous feedstock and outputting a residue, it can also take in partially processed carbonaceous reactant material from another gasifier and/or output its residue to another gasifier. In one embodiment of the invention, and referring to FIG. **10**, a horizontally (laterally) oriented gasifier is followed by a vertically oriented gasifier. In an alternate embodiment of the invention, and referring to FIG. **11**, a vertically oriented gasifier is followed by a horizontally (laterally) oriented gasifier. A worker skilled in the art will readily understand that the orientations and positions of the inputs and outputs to the gasifiers shown in FIGS. **10** & **11** are merely exemplary and are not intended to limit the orientations and positions of the inputs in an actual implementation of these systems.

Material Displacement Control Module

[0094] In contrast to standard descending bed gasifiers that rely on the gradual consumption of the reactant material in the gasifier to move the material downwards, the vertically oriented gasifier of the present invention actively controls the movement of the reactant material through the gasifier via a material displacement control module, thus allowing the overall gasification process to be enhanced, if not optimized for a given set of process conditions.

[0095] As will be described in greater detail below, the material displacement control module may further be associated with, or integrated within a local, regional and/or global control system adapted to actively control various elements of the gasifier in response to sensing one or more process characteristics, either within the gasifier, or external thereto, for example, in a downstream process or application of the product gas. In such an embodiment where the material displacement control module is actively operated in conjunction with a local, regional and/or global process control system, further refinement of the material processing may be achieved to meet downstream needs, for example, when the product gas, or a further processed derivative thereof, is used for a selected downstream application. Alternatively, or in combination therewith, the combined control of the gasification process may be implemented so to maximise gasification of the material, for example, to meet environmental regulations where such regulations exist, and/or to minimise an energetic impact of the process.

[0096] In general, the material displacement control module may be configured to operate under pre-set operational parameters, for example, allowing for a substantially constant residence time of the material in each processing region, or again, may be configured to operate under dynamically updated or generated operational parameters adapted to optimise processing of the material to achieve a given result. In either scenario, the material displacement control module, and any control system operatively coupled thereto, may comprise one or more sensing elements for sensing one or more process characteristics, such as process temperature(s), pressure(s), reactant composition, product gas composition, and adjust one or more process devices, such as mechanisms and/or devices operatively controlled by the material displacement control module for enabling a controlled displacement of the material through the processing regions within the gasifier, in response to these characteristics.

[0097] In general, the primary function of the material displacement control module is to promote the downward movement of the reactant material through the different processing regions of the gasifier in an actively controlled fashion in order to facilitate efficient overall gasification. It may also optionally incorporate means to break up residue agglomerates that can cause jamming at the residue outlet of the gasifier. The material displacement control module can be configured to operate one of a variety of mechanisms or devices known in the art for enabling displacement of material from one region to another. Examples include, but are not limited to rotating arms, rotating wheels, rotating paddles, moving shelves, pusher rams, screws, conveyors, and combinations thereof.

[0098] In addition to controlling the displacement of material through the gasifier, the material displacement control module can also be specifically optimized to also minimize the carbon content in the residue. In one embodiment of the invention, this is achieved using a plug flow pattern for the movement of the reactant material and a total control over the residue removal rate.

[0099] The factors involved in the choice of a particular type of device or mechanism operated by the material displacement control module include but are not limited to: (a) controllability & speed: how well can the flow of the reactant material through the gasifier be controlled accurately; (b) variance in reactor flow: if additives are added below the material displacement control module, is there a disruption to the flow and is the disruption manageable; and/or (c) power requirements and durability: how much energy and maintenance is required for proper operation of the device or mechanism, e.g. rotating grates require more maintenance than screws and pusher rams when properly designed.

[0100] FIG. **12** depicts one embodiment of the invention in which the material displacement control module comprises a rotating paddle **81** at the bottom of each processing chamber **20** which moves the reactant material out of the processing chamber **20** through a small residue outlet **70**. To avoid the waste of partially/unprocessed reactant material through the residue outlet **70** by a direct drop, a hat covering **82** is placed over the residue outlet **70**. Limit switches may be optionally used to control the speed of the bar rotation and thus the rate of removal of residue. A worker skilled in the art will readily understand that in embodiments where the multiple processing chambers are operatively coupled, a rotating paddle may be used at the bottom of only the lowermost processing chamber and the reactant material passes from the uppermost processing chamber to the lowermost processing chamber by the action of gravity.

[0101] FIG. **13**A depicts one embodiment of the invention in which the material displacement control module comprises a set of extractor screws **83** at the bottom of each processing chamber **20** which moves the residue out of the processing chamber **20**. Serration on the edge of the extractor screw flight helps in the breaking up of the residue agglomerations that could otherwise result in jamming at the residue outlet **70** of the gasifier **10**. A hat covering **82** is not required if the residue outlet **70** is moved away from the processing chamber **20**, as for the embodiment shown in FIG. **13**B. Limit switches may be optionally used to control the speed of the screws and thus the rate of removal of residue. A worker skilled in the art will readily understand that in embodiments where the multiple processing chambers are operatively coupled, a set of extractor screws may be used at the bottom of only the lowermost processing chamber and the reactant material passes from the uppermost processing chamber to the lowermost processing chamber by the action of gravity.

[0102] FIG. **14** depicts one embodiment of the invention in which the material displacement control module comprises a single thin pusher ram **85** for each processing chamber **20** which moves the residue out of the processing chamber **20** through a small residue outlet **70**. Depending on the position of the residue outlet **70**, a hat covering **82** may or may not be required as shown in FIG. **14**. Limit switches may be optionally used to control the length of the pusher ram stroke and thus the amount of residue moved with each stroke. The use of thin, pusher rams **85** is unlike lateral transfer gasifiers where the rams used are typically carrier-rams that carry large amounts of reactant material from one processing region to another. As the pusher rams **85** used are thin, only a small amount of residue is moved out of the processing chamber **20**. A worker skilled in the art will readily understand that in embodiments where the multiple processing chambers are operatively coupled, a pusher ram may be used at the bottom of only the lowermost processing chamber and the reactant material passes from the uppermost processing chamber to the lowermost processing chamber by the action of gravity.

[0103] In one embodiment of the invention with one or more processing regions being promoted by one or more additive input elements within each processing chamber, the material displacement control module may comprise an array of one or more pusher rams within each processing chamber, each of which is used to actively control the movement of the reactant material from one processing region to the next until the final pusher ram pushes the residue out of the processing chamber. Thus, the reactant material is actively controlled through the entire height of a single processing chamber. A worker skilled in the art will understand that such a material displacement control module can enable setting up of different 'residence times' in the different processing regions even within the same processing chamber.

[0104] In embodiments where the material displacement control module comprises a moving element and a guiding element, suitable moving elements include, but are not limited to, a shelf/platform, pusher ram, plow, screw element or a belt. The guide element can include one or more guide channels located in the bottom wall of the processing chambers, guide tracks or rails, guide trough or guide chains. Alternatively, the guide element can include one or more wheels or rollers sized to movably engage the guide element. In one embodiment of the invention, the guide engagement member is a sliding member comprising a shoe adapted to slide along the length of the guide track. Optionally, the shoe further comprises at least one replaceable wear pad.

[0105] The material displacement control module may be powered using a motor and drive system, or other such means as readily known in the art. In one embodiment the motor means is an electric variable speed motor which drives a motor output shaft selectably in the forward or reverse directions. Optionally, a slip clutch could be provided between the motor and the motor output shaft. The motor may further comprise a gear box.

[0106] Alternatively, operation of the material displacement control module can be implemented by a hydraulic or pneumatic system, chain and sprocket drive, or a rack and pinion drive. These methods of translating the motor rotary motion into linear motion have the advantage that they can be applied in a synchronized manner at each side of the material displacement control module (e.g. a pusher ram) to assist in keeping the mechanism aligned and thus minimize the possibility of jamming. In one embodiment, the use of two chains provides a means of maintaining angular alignment without the need for precision guides.

[0107] For the embodiments using two processing chambers, FIG. **16** shows a variety of different devices and/or mechanisms that can be used by the material displacement control module for displacement of reactant material from one processing chamber to another. A worker skilled in the art will understand that the options in this figure are merely exemplary and other appropriate designs for such devices/mechanisms can be considered to be within the scope and nature of the invention disclosed herein.

Processing Chambers

[0108] The vertically oriented gasifier comprises one or more processing chambers. The processing chamber can be chosen from a group consisting of fixed-bed processing chambers, gravity-induced vertical processing chambers, mechanically-assisted flow processing chambers, entrained flow processing chambers, and fluidised bed processing chambers, to name a few.

[0109] In fixed-bed processing chambers known to a worker skilled in the art, the feedstock enters the system from the top and rests on a surface through which input gas, such as heated air or steam (or other additives), may be communicated. The input gas passes through the feedstock bed in a counter-current fashion, from the bottom and all output gases, including off-gas, syngas, cooled air and steam, or volatiles, leaves the processing chamber through vents or other outlets at the top of the processing chamber. Any residue such as ash or char passes through the communicable surface and exits the processing chamber through the bottom portion.

[0110] In entrained flow processing chambers **22**, with reference to FIG. **17**, the input gas travels in a counter-current flow relative to the feedstock. Here, the feedstock is at least partially suspended by the movement of the additives, thereby promoting a more distributed contact between the input and the feedstock. The reaction occurs as the reactant material moves downward, driven by gravity, in opposition to the direction of travel of additives, the flow of which has sufficient force to partially suspend the descending feedstock. Output gases, including off-gas, syngas, cooled air, steam and other volatiles, exit at the top of the processing chamber, and the resulting residue exit at the bottom.

[0111] In fluidized bed processing chambers **24**, with reference to FIG. **18**, the feedstock is suspended in the upward moving additives similar to entrained flow processing chambers. The distinction however lies in the behaviour of the feedstock in the bed. In fluidized beds, the additives enter the processing chamber at velocities that greatly overcome any gravitational force, and the feedstock bed moves in a much more turbulent manner thereby causing a more homogeneous reaction region and behaving in a fashion similar to that of a turbulent fluid even though the feedstock may in fact be solid. The additives enter the processing chamber from the bottom, passes counter-current to the feedstock and output gases, including off-gas, syngas, cooled air and steams, or volatiles, leave the processing chambers at the top.

[0112] In one embodiment of the invention using a moving-bed processing chamber **26**, the processing chamber **26** comprises a feedstock input proximal to the top of the processing chamber, two or more additive input elements for injection of pre-heated air and positioned such that each promotes determination of a different processing region, a product gas outlet, a residue outlet and an actively controlled material displacement control module at the base of the processing chamber. In one embodiment and referring to FIG. **19**, separate additive input elements are also reserved for addition of steam into the processing chamber. Also, mixing mechanisms **27** may be used to promote enhanced interaction between the additives and the reactant material within the processing chamber.

[0113] In one embodiment of the invention using moving-bed processing chambers, the gasifier comprises two or more moving-bed processing chambers, each with an additive input element, or group thereof, for injection of pre-heated air at the bottom of the processing chamber. The injection of pre-heated air from the bottom enables the oxidation of char formed near the bottom of the processing chamber. The counter-current flow of the pre-heated air with respect to the feedstock also enhances the energy utilization. As the pre-heated air passing through the moving feedstock bed loses its temperature, a temperature gradient is formed within the processing chamber that is consistent with the higher temperatures needed for the latter processes of gasification.

[0114] In one embodiment of the invention using moving-bed processing chambers, the one or more additive input elements for each processing chamber are distributed all around the processing chamber. This distribution of a plurality of input elements allows finer control of the processes of gasification. FIGS. **20**A to **20**D show other embodiments of the invention with differences in the placement and type of additive input elements. The general shapes of the processing regions for each case are also shown.

[0115] The processing chambers used can be of any shape so long as the internal volume is sufficient to accommodate the appropriate amount of reactant material for the designed residence time, and sufficient for a reasonable gas superficial velocity to be attained. In one embodiment of the invention, the processing chamber is a refractory-lined cylinder and its length is between about 1 and 3 times its diameter. In one embodiment, its length is between about 1 and 2 times its diameter. In one embodiment, its length is about 1.5 times its diameter.

[0116] In one embodiment of the invention, the processing chamber has a cylindrical outer wall and a refractory-lined, downward sloping, inner walls. FIGS. **21**A and **21**B show a few more possible shapes for the processing chamber. Other appropriate shapes will be apparent to a worker skilled in the art.

[0117] The refractory lining protects the processing chamber from the effects of high temperatures and corrosive gases and minimizes unnecessary loss of heat from the process. The refractory material is a conventional refractory material, which is well-known to those skilled in the art and which is suitable for use for a high temperature e.g. up to about 1800° C., un-pressurized reaction. Examples of such refractory material include, but are not limited to, 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 processing chamber from the impact of corrosive gases, it may be lined with a 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 gasifier requirements.

[0118] The roof or upper portion of the processing chamber should also be designed for the optimal flow and residence time of gas. The roof portion can be flat, domed or other practical configurations that promote the flow of gas through the processing chamber, and thus the avoidance of dead (a.k.a 'cold') spots.

[0119] The physical design characteristics of a processing chamber are determined by a number of factors that can be readily determined by one skilled in the art. For example, the internal configuration and size of the processing chamber are dictated by the operational characteristics through analyses of the chemical composition of the input feedstock to be processed. Other design factors include the type of heating means used and the position and orientation of the heating means used. These heating means are generally positioned within the processing chamber at the desired depth in order to concentrate the high temperature processing region where it will be most effective, while at the same time minimizing heat losses. Sometimes, other additives such as steam are added into the gasifier in addition to the pre-heated air, to improve the quality of the product syngas. The position, orientation and number of the injection ports for these additional additives also have to be considered in the design of the processing chamber to ensure that they are injected where they will promote efficient reaction to achieve the desired conversion result.

[0120] A worker skilled in the art will readily understand that the one or more processing chambers used in the vertically oriented gasifier can each use different refractory materials, different shapes, different sizes and different material displacement control modules as suitable for the processing done within that chamber.

[0121] Various computer-based simulation and modeling tools can facilitate the physical design of the processing chamber by taking into account factors such as efficient heat transfer, gas flow, mixing of additives, etc. Computer-based tools virtually eliminate the need for experimentation prior to preliminary system design and provide rapid confirmation of process characteristics and efficiency with any input waste stream. They also permit interactive iteration to optimize operational characterization for any particular system prior to system commissioning and facilitate real-time optimization of processes for non-homogeneous materials based on product gas characterization as input.

[0122] One such simulator is the Chemical Process Simulator, as detailed in U.S. Pat. No. 6,817,388 (incorporated by reference). It uses the principle of minimization of Gibb's free energy to allow prediction of the product gas components at a specific temperature and specific set of input parameters. In general, the simulator consists of three main computational blocks:

[0123] a. An Ideal Reaction Model: This calculates the ideal, steady state equilibrium composition of the product gas, by minimizing the Gibbs free energy of the product chemical species in adiabatic, isobaric equilibrium. A generalized Gibbs minimization approach is used here to find the equilibrium composition of arbitrary large systems without the need to write equilibrium reactions.

[0124] b. A Carbon Deposition Model: This calculates the amount of soot (solid Carbon C(s)) formed, or the amount of steam needed to eliminate soot formation by comparing the input composition vs. equilibrium curves. This model can also be used to recursively solve for the amount of water that must be added in order to reduce the amount of solid carbon formed.

[0125] c. A Non-Ideal Reaction Model: This determines the amount of methane, acetylene and ethylene that is formed in excess of the ideal as calculated by multiplying the amount of Carbon in the system by experimentally derived ratios. This approximates the result of non-total decomposition of long-chain hydrocarbons or polymers.

[0126] In addition to using the Chemical Process Simulator, flow modeling of the processing chamber may also be used in the design process to ensure proper mixing of the process inputs, to analyze impact of the kinetic effects, and to adjust the reaction temperature profile within the simulator. Flow modeling results also assist refractory design since all operating characteristics at the refractory surface can readily be identified.

[0127] Optionally, and as mentioned earlier, one or more of the one or more processing chambers of the gasifier may comprise a mixing means for ensuring efficient exposure of the reactant material to the pre-heated air thus allowing efficient gasification. The mixing means prevents gas channeling, a condition where the additive inputs such as pre-heated air burns a path through the bed, resulting in more pre-heated air travelling down that 'channel' avoiding the reactant material completely. The passage of pre-heated air into the gas phase, also called breakthrough, can cause rapid combustion with gas phase combustibles, agglomeration of the reactant material and channel burning. Good mixing also stabilizes the gas composition and reduces the risk of downstream gas explosion.

[0128] Gasification requires heat and an oxidant such as oxygen or steam. Heating can occur either directly by the heat released due to partial oxidation of the feedstock or indirectly by use of a heat source known in the art.

[0129] In one embodiment of the invention, the heat source is pre-heated air added into the processing chambers through the additive input elements. The air is either obtained from air heaters or heat exchangers, both of which are known to a worker skilled in the art and fed through to each processing region using an independent air feed and distribution system such as an air box. Alternatively, the indirect heat source could either be circulating hot sand or an electrical heating element.

[0130] In order to facilitate initial start up of the gasifier, the processing chambers can include access ports sized to accommodate various conventional burners, for example natural gas or propane burners, to pre-heat the gasifier.

[0131] In addition, the processing chambers can further comprise one or more service ports to allow for entry for maintenance and repair. Such ports are known in the art and can include sealable port holes of various sizes. In one embodiment, access to the processing chamber is provided by a manhole at one end which can be closed by a sealable refractory lined cover during operation. In one embodiment of the invention, a manhole is placed on both ends of the processing chamber for maintenance.

Additive Input Elements

[0132] As mentioned earlier, additives may be added to each of the one or more processing chambers of the vertically oriented gasifier to facilitate efficient conversion of feedstock into product gas. The type and quantity of the additives is selected to optimize the process reactions while maintaining adherence to regulatory authority emission limits and minimizing operating costs. The different types of additive input elements include but are not limited to air, oxygen-enriched air, oxygen, steam and ozone. The additive input elements play a key role in determining the temperatures within the processing chambers and thus the extents of the processing regions wherein different processes are at least partially favoured.

[0133] Air or oxygen input can be used to maximize carbon conversion (i.e., minimize free carbon) and to maintain the optimum processing temperatures while minimizing the cost of input heat. The quantity of both additives can be established and rigidly controlled as identified by the outputs for the feedstock being processed. The amount of air injection is established to minimize the cost of heating while ensuring the overall process does not approach any of the undesirable traits associated with incineration (such as unwanted dioxins, furans, NOx, SOx in product gas, metals in ash and lower carbon conversion), and satisfies the emission standards requirements of the local area.

[0134] Steam inputs promote sufficient free oxygen and hydrogen to maximize the conversion of decomposed elements of the feedstock into product gas and/or non-hazardous compounds. As the conversion of the reactant material to gas via reaction with steam is an endothermic one, it can serve to balance out the endothermic nature of the reaction via air. In addition, steam provides additional hydrogen for the proper balancing of C, H, O reactions.

[0135] In some embodiments of the invention, a secondary feedstock stream is also introduced as a process additive. This feedstock stream can be dynamically manipulated by the global control system depending on the downstream parameters of the gasifier such as the quality of the product gas, pressure etc as sensed by the sensing elements. A typical secondary feedstock is high carbon feedstock such as plastics.

[0136] Each of the processing chambers therefore, may include a plurality of additive input elements that include inlets for steam injection and/or air injection. The steam inlets can be strategically located to direct steam into high temperature regions and into the product gas mass just prior to its exit from the processing chamber.

[0137] The additive input elements can be strategically located to ensure full coverage into the processing regions. In one embodiment, they are located proximal to the floor of the processing chamber. Alternatively, they are located either in the floor of the processing chamber or are distributed all around the walls of the processing chamber. In embodiments in which pre-heated air is used as the gasifier heating means, additional air/oxygen injection input elements may optionally be included.

[0138] The actual location of the additive input elements may determined based on any number of the following factors: (a) maximize heat transfer; (b) maximize contact with carbon; (c) minimize pressure loss; (d) avoid pluggage; (e) minimize potential for gas channeling.

[0139] For embodiments of the invention where additives are added from the top of the processing chamber, the gases added at the top may help dry the wet carbonaceous feedstock at the top of the bed or help in the distribution of the material by the use of jets (by spraying the material around the top of the pile, rather than the use of mechanical agitation means). If air or hot steam is added at the top, the temperature of the product gas increases resulting in the breakdown of tars in the gas phase. Alternatively, the addition of low temperature steam or nitrogen (or other liquid fluids) lowers the gas temperatures and protects the downstream equipment. The major drawback of having the additive input elements on the top of the chamber is however the risk of dilution of the product gas.

[0140] For embodiments of the invention where additives are added from the bottom of the processing chamber, the residence time of the additives in the processing chamber is maximised, which can be beneficial in low-temperature systems with slower reactions. While poor designs run a high risk of producing slag, agglomerations, etc. that interfere with operations, proper design can reduce the likelihood of these problems. The injection of additives at the bottom promotes that the entire processing chamber is affected and that the carbon is removed from the ash before it exits the processing chamber.

[0141] For embodiments of the invention where additives are added from the sides of the processing chamber, even distribution of additives and hence more stable reactions are promoted. This design also evens out the processing regions and reduces the concentration of some additives (such as oxygen or ozone) to avoid localized combustion or agglomeration. However, the main drawback is that the additives injected along the sides do not reach the middle of the processing chamber unless high flow rates are used which tend to fluidize the bed or create hot spots near the walls. Agitators can be used to promote mixing of the reactant material from the middle with that of the sides.

Feedstock Input Means

[0142] The vertically oriented gasifier includes a material feeder system comprising one or more input feed ports catered to any physical characteristics of the input feedstock, each of which feed directly into the gasifier. In one embodiment of the invention, the material feeding subsystem consists of a feed hopper and a screw conveyor used to transport feedstock to the gasifier. In some embodiments of the invention, the material fed into the vertically oriented gasifier can be partially processed reactant material from an upstream gasifier. The feed hopper acts as a buffer for the material ready to be fed into the gasifier. The hopper can optionally have high and low level indicators that control the flow into the hopper and are optionally under the control of the process controller to match the feed rate to process demands.

[0143] Optionally, referring to FIG. **22**A, the material feeding subsystem can further comprise an additional entry to accept a secondary feed (usually high carbon feedstock such as shredded plastic), thereby enabling quick response to process demands for higher or lower carbon input to meet the required gas quality for the downstream applications.

[0144] Referring to FIG. **22**, various embodiments of the invention can be envisioned, whereby the different feed streams are either mixed together in a common hopper before insertion into the gasifier or not. Optionally, the gasifier has a separate feeding subsystem for feeding the high carbon feedstock into the gasifier. Also, a more general case can be considered where there are more than two feed streams as well.

[0145] In one embodiment of the invention, the material feeding system consists of a rectangular feedhopper and a hydraulic assisted ram. A gate may be installed in the middle of the feed chute to act as a heat barrier between the processing chamber and the feedhopper. Limit switches on the feeder control the length of the ram stroke so that the amount of material fed into the processing chamber with each stroke can be controlled.

[0146] In one embodiment of the invention, the primary material feeding system may also be modified to accommodate the feeding of boxes, the form in which hospital biomedical type waste is provided for processing. A rectangular double door port will permit the boxes to be fed into the primary feed hopper where the hydraulic ram can input them into the processing chamber.

[0147] In one embodiment of the invention, an auger can be inserted hydraulically into the processing chamber to provide a granular waste material feed. In addition, ram, rotary valve, top gravity feed, are examples of other feeders that can be used in the present context to facilitate the introduction of desired feedstocks. In addition, liquids and gases can be fed into the processing chamber simultaneously through their own dedicated ports.

[0148] Optionally, the feedstock will pass through a pre-processing system before being fed into the feedstock input means. The pre-processing subsystem may comprise a shredder to reduce the as-received feedstock to a size more suitable for processing. As, components of the feedstock may include materials large enough to jam the shredder, the shedder is optionally equipped to stop when a jam is sensed, automatically reverse to clear the jam and then restart. If a jam is still detected the shredder will shut-down and send a warning signal to the controller. Appropriate shedder and shedder designs are known in the art.

[0149] The pre-processing subsystem may also include a magnetic pick-up located above the conveyor to avoid the undesirable feeding of excessive amounts of metal through the gasifier. Appropriate magnetic pick-ups are known in the art and consist of a powerful magnet over a pick conveyor belt to attract any ferrous metal that may be present in the shredded waste. Optionally, a non-magnetic belt can run across the direction of the pick conveyor, between the magnet and the feedstock so that any metal attracted to the magnet gets moved laterally away from the feedstock stream. When the metal has been moved away from the magnet it can be dropped onto a pile that is either disposed or sold.

Gas Outlet

[0150] In one embodiment of the invention, the off-gas generated in each processing chamber **20** is taken out using a gas outlet **60** that is at the top of the processing chamber **20**. The off-gas streams from the different processing chambers **20** may be kept separate or merged before being sent either to a storage tank for future use or for further processing in a gas reformulating system (GRS) **92**, as shown in FIG. **23**C. Alternatively, the gas outlet is placed at the bottom of the processing chamber and the product gas is drawn out using a blower kept downstream or other suction means as known in the art. A worker skilled in the art will readily understand that the placement of the gas outlet at other positions within the processing chambers are all considered to be within the scope of the invention, even if not explicitly mentioned herein.

[0151] In one embodiment of the invention, the gasifier is connected to a gas reformulating system (GRS) **92** either directly or via piping for the reformulating of input gas derived from gasification of carbonaceous feedstock into reformulated gas of a defined chemical composition. In particular, the gas reformulating system uses torch heat from one or more plasma torches to dissociate the gaseous molecules thereby allowing their recombination into smaller molecules useful for downstream application, such as energy generation. At the high temperatures, typically 900° C.-1200° C., provided by the plasma torches, 'tar cracking' usually occurs to eliminate the tar as well. The system may also comprise gas mixing means, process additive means, and a control system with one or more sensors, one or more process effectors and computing means to monitor and/or regulate the reformulating reaction. Referring to FIG. **23**, the syngas produced in the GRS may be sent to a gas conditioning system (GCS) **90** and/or a gas homogenization system (GHS) and/or a storage tank.

[0152] In other embodiments of the invention, low temperature gas reformulating systems can be used which do not result in tar cracking but result in the conversion of the gas to a different composition tailored for a particular downstream application.

[0153] The GCS **90** serves to remove particulate matter and other impurities from the syngas while the GHS serves to smooth out any time variations in the composition and pressure of the syngas by providing adequate mixing means and residence time within a homogenization chamber. A storage tank is optionally used if the conditioned, homogenized syngas needs to be stored for future use. Otherwise, the conditioned, homogenized syngas can be used for downstream applications such as gas engines, boilers etc. Excess syngas can also be disposed of safely using a flare stack.

Residue Outlet

[0154] The residue outlet **70** is used to remove the residue out of the final processing region **40** of the gasifier **10**. The configurations in which the residue exit the processing chamber are dependent on the design and function of the subsequent process and can be readily determined by one skilled in the art.

[0155] As mentioned earlier, the residue is removed from the gasifier by the material displacement control module. In different embodiments of the invention, the residue can be removed into, for example, an ash collection gasifier or to a water tank for cooling as is known in the art, from where it is transmitted through a conduit under control of a valve, to a point of discharge. In one embodiment of the invention, the residue from the vertically oriented gasifier is sent to another gasifier for further gasification. This is useful if the vertically oriented gasifier is not able to achieve thorough volatilization and carbon conversion.

[0156] In one embodiment of the invention and referring to FIG. **24**, the residue is moved to a residue conditioning system **94** which is either directly connected to the gasifier **10** or connected via a conveyor. In the residue conditioning system **94**, plasma arc heating is used to convert the residue (char, ash) to slag by raising the temperature of the residue to the level required for complete melting and homogenization to guarantee trouble free, continuous and automatic (i.e. unattended) slag removal. Other heating mechanisms can also be used in other embodiments of the residue conditioning system. The molten slag is quenched in a water tank to form a vitreous, solid slag that can either be used in the construction industry or disposed off in a non-hazardous manner in landfills. Referring to FIG. **25**, any product gases generated in the residue conditioning system **94** is sent to the GCS **90** either after passing through the GRS **92** or otherwise.

[0157] Additionally, referring to FIG. **26**, the residual particles collected in the GCS **90**, can be sent back to the residue conditioning system **94** for conversion to molten slag and quenching. For the case of the transfer of the product gas from the residue conditioning system **94** to the GCS **90** without passing through the GRS **92**, the gas can reach the GCS **90** either directly or through a secondary GCS **96**, as shown in FIG. **26**.

[0158] In one embodiment of the invention and referring to FIG. **27**, the overall system is constructed using a modular approach where the product gas output from the plurality of processing chambers **20** of the gasifier are not combined to pass through a single GRS and GCS but is split up into two parallel streams, each with its own GRS **92** and GCS **90**. A worker skilled in the art will understand that FIG. **27** is merely exemplary and that other designs of the overall systems using interconnections of the different components of the multiple parallel processing streams can be considered to be within the scope and nature of the invention disclosed herein.

[0159] FIGS. **28** and **29** shows the particular implementation of the gasifier where a residue conditioning system **94** based on a plasma-torch **95** is interfaced in a vertically successive fashion to a gasifier comprising either one or two vertically successive processing chambers **20**.

[0160] As mentioned earlier, the gasifier **10** of the invention can be combined with various other systems, such as a residue conditioning system **94**, gas reformulating system **92**, gas conditioning system **90**, gas homogenization system, to form a complete gasification facility. This facility will take in carbonaceous feedstock and convert it into a refined, conditioned and homogenized syngas that can be used for various downstream applications. The overall gasification facility can be controlled using a global control system **98** as described above to ensure that the overall process meets the requirements set by the particular downstream application and by the relevant regulatory standards. One embodiment of a control system for an overall gasification facility is shown in FIG. **30**.

Control System

[0161] A control system **98** is generally provided to control one or more processes implemented in, and/or by, the vertically oriented gasifier, or affecting any downstream process or application of the gas produced thereby, and/or provide control of one or more process devices contemplated herein for affecting such processes. In general, the control system may operatively control various processes related to the vertically oriented gasifier and/or related to one or more global, upstream and/or downstream processes implemented within a gasification system comprising such a gasifier, and thereby adjusts various control parameters thereof adapted to affect these processes for a defined result. Various sensing elements and response elements may therefore be distributed throughout the controlled system(s), or in relation to one or more components thereof, and used to acquire various process, reactant and/or product characteristics, compare these characteristics to suitable ranges of such characteristics conducive to achieving the desired result, and respond by implementing changes in one or more of the ongoing processes via one or more controllable process devices.

[0162] The control system generally comprises, for example, one or more sensing elements for sensing one or more characteristics related to the system(s), processe(s) implemented therein, input(s) provided therefor, and/or output(s) generated thereby. One or more computing platforms are communicatively linked to these sensing elements for accessing a characteristic value representative of the sensed characteristic(s), and configured to compare the characteristic value(s) with a predetermined range of such values defined to characterise these characteristics as suitable for selected operational and/or downstream results, and compute one or more process control parameters conducive to maintaining the characteristic value within this predetermined range. A plurality of response elements may thus be operatively linked to one or more process devices operable to affect the system, process, input and/or output and thereby adjust the sensed characteristic, and communicatively linked to the computing platform(s) for accessing the computed process control parameter(s) and operating the process device(s) in accordance therewith.

[0163] In one embodiment, the control system provides a feedback, feedforward and/or predictive control of various systems, processes, inputs and/or outputs related to the conversion of carbonaceous feedstock into a gas, so to promote an efficiency of one or more processes implemented in relation thereto. For instance, various process characteristics may be evaluated and controllably adjusted to influence these processes, which may include, but are not limited to, the heating value and/or composition of the feedstock, the characteristics of the product gas (e.g. heating value, temperature, pressure, flow, composition, carbon content, etc.), the degree of variation allowed for such characteristics, and the cost of the inputs versus the value of the outputs. Continuous and/or real-time adjustments to various control parameters, which may include, but are not limited to, heat source power, additive feed rate(s) (e.g. oxygen, oxidants, steam, etc.), feedstock feed rate(s) (e.g. one or more distinct and/or mixed feeds), gas and/or system pressure/flow regulators (e.g. blowers, relief and/or control valves, flares, etc.), material displacement within the gasifier (e.g. between vertically successive processing regions), and the like, can be executed in a manner whereby one or more process-related characteristics are assessed and optimized according to design and/or downstream specifications.

[0164] Alternatively, or in addition thereto, the control system may be configured to monitor operation of the various components of a given system for assuring proper operation, and optionally, for ensuring that the process(es) implemented thereby are within regulatory standards, when such standards apply.

[0165] In accordance with one embodiment, the control system may further be used in monitoring and controlling the total energetic impact of a given system. For instance, a given system may be operated such that an energetic impact thereof is reduced, or again minimized, for example, by optimising one or more of the processes implemented thereby, or again by increasing the recuperation of energy (e.g. waste heat) generated by these processes. Alternatively, or in addition thereto, the control system may be configured to adjust a composition and/or other characteristics (e.g. temperature, pressure, flow, etc.) of a product gas generated via the controlled process(es) such that such characteristics are not only suitable for downstream use, but also substantially optimised for efficient and/or optimal use. For example, in an embodiment where the product gas is used for driving a gas engine of a given type for the production of electricity, the characteristics of the product gas may be adjusted such that these characteristics are best matched to optimal input characteristics for such engines.

[0166] In one embodiment, the control system may be configured to adjust a given process such that limitations or performance guidelines with regards to reactant and/or product residence times in various components, or with respect to various processes of the overall process are met and/or optimised for. For example, an upstream process rate may be controlled so to substantially match one or more subsequent downstream processes. Namely, the residence time of the material within the gasifier, and/or processing regions thereof, may be set and/or dynamically adjusted by a material displacement control module, which may operate independently, cooperatively and/or as a submodule of an overall or global control system, to meet certain preferences and/or requirements of downstream processes and/or applications.

[0167] The control system can be adapted for maintaining conditions suitable for local and/or downstream needs, e.g., temperature, feedstock input rate, displacement of material, etc. can be controlled to meet local needs, such as fast processing of waste, and/or to meet downstream needs such as suitable gas composition.

[0168] In addition, the control system may, in various embodiments, be adapted for the sequential and/or simultaneous control of various aspects of a given process in a continuous and/or real time manner.

[0169] In general, the control system may comprise any type of control system architecture suitable for the application at hand. For example, the control system may comprise a substantially centralized control system, a distributed control system, or a combination thereof. A centralized control system will generally comprise a central controller configured to communicate with various local and/or remote sensing devices and response elements configured to respectively sense various characteristics relevant to the controlled process, and respond thereto via one or more controllable process devices adapted to directly or indirectly affect the controlled process. Using a centralized architecture, most computations are implemented centrally via a centralized processor or processors, such that most of the necessary hardware and/or software for implementing control of the process is located in a same location.

[0170] A distributed control system will generally comprise two or more distributed controllers which may each communicate with respective sensing and response elements for monitoring local and/or regional characteristics, and respond thereto via local and/or regional process devices configured to affect a local process or sub-process. Communication may also take place between distributed controllers via various network configurations, wherein a characteristics sensed via a first controller may be communicated to a second controller for response thereat, wherein such distal response may have an impact on the characteristic sensed at the first location. For example, a characteristic of a downstream product gas may be sensed by a downstream monitoring device, and adjusted by adjusting a control parameter associated with the converter that is controlled by an upstream controller. In a distributed architecture, control hardware and/or software is also distributed between controllers, wherein a same but modularly configured control scheme may be implemented on each controller, or various cooperative modular control schemes may be implemented on respective controllers.

[0171] Alternatively, the control system may be subdivided into separate yet communicatively linked local, regional and/or global control subsystems. Such an architecture could allow a given process, or series of interrelated processes to take place and be controlled locally with minimal interaction with other local control subsystems. A global master control system could then communicate with each respective local control subsystems to direct necessary adjustments to local processes for a global result.

[0172] The control system of the present invention may use any of the above architectures, or any other architecture commonly known in the art, which are considered to be within the general scope and nature of the present disclosure. For instance, processes controlled and implemented within the context of the invention may be controlled in a dedicated local environment, with optional external communication to any central and/or remote control system used for related upstream or downstream processes, when applicable. Alternatively, the control system may comprise a sub-component of a regional and/or global control system designed to cooperatively control a regional and/or global process. For instance, a modular control system may be designed such that control modules interactively control various sub-components of a system, while providing for inter-modular communications as needed for regional and/or global control.

[0173] The control system generally comprises one or more central, networked and/or distributed processors, one or more inputs for receiving current sensed characteristics from the various sensing elements, and one or more outputs for communicating new or updated control parameters to the various response elements. The one or more computing platforms of the control system may also comprise one or more local and/or remote computer readable media (e.g. ROM, RAM, removable media, local and/or network access media, etc.) for storing therein various predetermined and/or readjusted control parameters, set or preferred system and process characteristic operating ranges, system monitoring and control software, operational data, and the like. Optionally, the computing platforms may also have access, either directly or via various data storage devices, to process simulation data and/or system parameter optimization and modeling means. Also, the computing platforms may be equipped with one or more optional graphical user interfaces and input peripherals for providing managerial access to the control system (system upgrades, maintenance, modification, adaptation to new system modules and/or equipment, etc.), as well as various optional output peripherals for communicating data and information with external sources (e.g. modem, network connection, printer, etc.).

[0174] The processing system and any one of the sub-processing systems can comprise exclusively hardware or any combination of hardware and software. Any of the sub-processing systems can comprise any combination of none or more proportional (P), integral (I) or differential (D) controllers, for example, a P-controller, an I-controller, a PI-controller, a PD controller, a PID controller etc. It will be apparent to a person skilled in the art that the ideal choice of combinations of P, I, and D controllers depends on the dynamics and delay time of the part of the reaction process of the gasification system and the range of operating conditions that the combination is intended to control, and the dynamics and delay time of the combination controller. It will be apparent to a person skilled in the art that these combinations can be implemented in an analog hardwired form which can continuously monitor, via sensing elements, the value of a characteristic and compare it with a specified value to influence a respective control element to make an adequate adjustment, via response elements, to reduce the difference between the observed and the specified value. It will further be apparent to a person skilled in the art that the combinations can be implemented in a mixed digital hardware software environment. Relevant effects of the additionally discretionary sampling, data acquisition, and digital processing are well known to a person skilled in the art. P, I, D combination control can be implemented in feed forward and feedback control schemes.

[0175] In corrective, or feedback, control the value of a control parameter or control variable, monitored via an appropriate sensing element, is compared to a specified value or range. A control signal is determined based on the deviation between the two values and provided to a control element in order to reduce the deviation. It will be appreciated that a conventional feedback or responsive control system may further be adapted to comprise an adaptive and/or predictive component, wherein response to a given condition may be tailored in accordance with modeled and/or previously monitored reactions to provide a reactive response to a sensed characteristic while limiting potential overshoots in compensatory action. For instance, acquired and/or historical data provided for a given system configuration may be used cooperatively to adjust a response to a system and/or process characteristic being sensed to be within a given range from an optimal value for which previous responses have been monitored and adjusted to provide a desired result. Such adaptive and/or predictive control schemes are well known in the art, and as such, are not considered to depart from the general scope and nature of the present disclosure.

[0176] Sensing elements contemplated within the present context, as defined and described above, can include, but are not limited to, temperature sensing elements, position sensors, proximity sensors, pile height sensors and means for monitoring gas.

[0177] In one embodiment, the gasifier comprises a temperature sensor array of one or more removable thermocouples. The thermocouples can be strategically placed to monitor temperature at various points within each processing region of the gasifier.

[0178] Appropriate thermocouples are known in the art and include bare wire thermocouples, surface probes, thermocouple probes including grounded thermocouples, ungrounded thermocouples and exposed thermocouples or combinations thereof.

[0179] In one embodiment of the invention, individual thermocouples are inserted into the chamber via a sealed end tube (thermowell) which is then sealed to the vessel shell, allowing for the use of flexible wire thermocouples which are procured to be longer than the sealing tube so that the junction (the temperature sensing point) of the thermocouple is pressed against the end of the sealed tube to assure accurate and quick response to temperature change. Optionally, to prevent material from getting blocked by the thermocouple tube the end of the sealed tube cap can be fitted with a deflector. In one embodiment, the deflector is a square flat plate, with bent corners that contact the refractory and are in-line with reactant material flow to slip-stream particles over the thermowell.

[0180] In addition, the invention may comprise devices for monitoring the exit of product gas. These may include but are not limited to gas composition monitors and gas flow meters. For example, as depicted in FIG. **30**, a gas analyser is provided downstream from the gasifier enabling analysis of the product gas, in this embodiment before homogenization for downstream use, in order to regulate various aspects of the gasification process. For example, when it is determined that the carbon content of the product gas is insufficient, an increase in the high carbon fee rate (e.g. plastics in feedstock input), when available, is increased accordingly. In another example, when the heating value of the product gas (e.g. high heating value, low heating value) is determined to be too low, the feed rate and additive input ratio may be adjusted, or again, the high carbon feed rate to MSW feed rate adjusted.

[0181] Similarly, a gas flow or pressure monitor may be used in an embodiment where a selected downstream application is adversely affected by variations and/or absolute fluctuations in gas flow/pressure. In response to a sensed variation in product gas pressure, for example, additive input feed rates may be adjusted, thereby adjusting the gas output of the gasifier. In response to such adjustment, other process characteristics, such as feedstock input rate, HCF input rate, process temperature, etc. may also be adjusted to rebalance the process and substantially maintain desired output characteristics.

[0182] Furthermore, by measuring process temperatures throughout the material pile, gas phase temperatures above the pile, and by measuring resultant off-gas flowrate and analyzing off-gas composition, the amount of air injected can be optimized to maximize efficiency and minimize undesirable process characteristics and products including slagging of ash, combustion, poor off-gas heating value, excessive particulate matter and dioxin/furan formation thereby meeting or bettering local emission standards. Such measurements can be taken during initial start-up or initial testing of the gasifier, periodically or continually during operation of the gasifier and may optionally be taken in real time.

[0183] In one embodiment of the invention, the gasifier can optionally comprise a pressure sensor or monitor within the gasifier.

[0184] The gasifier can further comprise level switches or monitors to assess pile height. Appropriate level switches, sensors and monitors are known in the art. In one embodiment of the invention, the level instrumentation comprises point-source level switches. In one embodiment of the invention, the level switches are microwave devices with an emitter on one side of the processing chamber and a receiver on the other side, which detects either presence or absence of solid material at that point inside the processing chamber.

[0185] A worker skilled in the art would readily be able to determine the appropriate placement of level switches, sensors and monitors such that the desired reactant material pile profile can be obtained. In one embodiment, the gasifier further comprises proximity or position sensors.

[0186] Response elements contemplated within the present context, as defined and described above, can include, but are not limited to, various control elements operatively coupled to process-related devices 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 elements controlling chamber heating, elements controlling the input of additives, feedstocks and other process constituents, and elements of the material displacement control module, to name a few.

[0187] The material displacement control module may be used in such embodiments to regulate the pile height inside a given chamber of the gasifier. Low levels of the feedstock pile can result in fluidization of the reactant material from injection of pre-heated air while high levels of the feedstock pile can result in poor temperature distribution through the reactant material pile due to restricted airflow. Therefore, a level control system with the use of a series of level switches may be used to maintain stable pile height inside the gasifier. Maintaining stable level also maintains consistent residence time in the gasifier.

[0188] The material displacement control module may be used as necessary to ensure that pile height is controlled at the desired level. To accomplish this in embodiments in which the material displacement control module comprise pusher rams, the pusher rams move in a series of programmed step of which there may exist a number of control parameters that may include, but are not limited to: specific movement sequence, speed, distance, and sequence frequency.

[0189] In some embodiments, the pusher rams move out to a set point distance, or until a controlling level switch is tripped; either at the same time or in a pre-determined sequence. The level switch control action can be based on a single switch, tripping either empty or full, or may require multiple switches tripping, empty or full, or any combination thereof. Afterwards, the pusher rams move back to end the cycle, and the process is repeated. There is an optional delay between cycles as required by the process and residence time requirements of the gasifier.

[0190] In one embodiment of the invention where the material displacement control module comprises an array of pusher rams in each processing chamber, the height of the reactant material pile in the processing chamber is a function of the input feed-rate and the pusher ram motion. Optionally, one processing chamber has three processing regions and the material displacement control module has three pusher rams with one pusher ram dedicated to each of the three processing regions for the movement of reactant material/residue out of that processing region. The third pusher ram controlling the movement of the residue out of the third processing region of the processing chamber sets the throughput by moving at a fixed stroke length and frequency to discharge the residue out of the processing chamber. The second pusher ram follows and moves as far as necessary to push reactant material onto the third processing region and change the third processing region's start-of-stage level switch state to "full". The first pusher ram follows and moves as far as necessary to push reactant material onto the second processing region and change the second processing region's start-of-stage level switch state to "full". All three pusher rams are then withdrawn simultaneously, and a scheduled delay is executed before the entire sequence is repeated. Additional configuration may be used to limit the change in consecutive stroke lengths to less than that called for by the level switches to avoid excess ram-induced disturbances. The pusher rams will always need to be moved fairly frequently in order to prevent over-temperature conditions at the bottom of the processing chamber.

[0191] A worker skilled in the art will readily understand that the same pusher ram sequence mentioned above is applicable also when the three processing regions are distributed across three processing chambers with one pusher ram per processing region. Appropriate pusher ram sequences can be readily developed for different embodiments of the gasifier and are considered to be within the scope of this invention.

[0192] As with controlled pusher ram sequences between processing regions and/or chambers, different material movement units (e.g. mechanisms, devices, etc.) may also be used in a given sequence and/or according to control parameters of the material movement control module at least partially influenced by pile height readings. For example, rotary arm configurations controlling movement of material between distinct chambers may be used in step to adjust pile heights within respective processing regions, as can others of the above examples, as will be apparent to the person of skill in the art. The control system may be further configured to assess optimal processing characteristics, taking into account optimal residence times of material within each region, pile height restrictions and favourable conditions, as well as other characteristics as described herein for a given process result.

[0193] Optionally, the control system may further provide for the control of temperature within the gasifier. For example, to promote optimisation of the conversion efficiency, the feedstock should be kept at as high a temperature as possible, for as long as possible. However, at very high temperatures, the material begins to melt and agglomerate forming 'clinkers' which affects the gasification performance in multiple ways: (1) it reduces the available surface area and hence the conversion efficiency; (2) it causes the airflow in the reactant material pile to divert around the chunks of agglomeration, aggravating the temperature issues and further accelerating the agglomeration process; (3) it interferes with the normal operation of the material displacement control module; and (4) it can jam the residue removal mechanisms thus potentially causing a system shut down.

[0194] In order to get the best possible conversion efficiency, the temperatures in the gasifier and temperature distribution through the pile can be stabilized and controlled. Stable temperature distribution throughout the reactant material pile may also be used to prevent a second kind of agglomeration, in which plastic melts and acts as a binder for the rest of the reactant material.

[0195] In one embodiment, temperature control within the pile is achieved by changing the flow of process air into a given region (ie. more or less combustion). For example, the process air flow provided to each processing region in the gasifier may be adjusted by the control system to stabilize temperatures at that region. Temperature control utilizing displacement units may also be used to break up hot spots and to avoid bridging.

[0196] In one embodiment, the air flow at each processing region is pre-set to maintain substantially constant temperature ranges and ratios between processing regions. Alternatively, air input ratios may be varied dynamically to adjust temperatures and processes occurring within each processing region of the gasifier and/or within the GRS.

[0197] The means for controlling the reaction conditions to manage the chemistry and energetics of the gasification of a feedstock comprise a main integrated processor and a series of sensors for monitoring the state of the system and control systems for controlling various operational parameters, for example, the rate of addition of feedstock and/or additives, as well as operating conditions, such as pressure in the processing chamber. The main integrated processor receives data obtained from sensors relating to current states of the gasification reaction, and processes these data to generate an appropriate set of output instructions to manage the chemistry and energetics of the conversion reaction, whereby the optimal reaction set point is maintained.

[0198] In response to the information input, the conditions within the gasifier can be adjusted either manually or automatically. The gasifier can be regulated by a series of on/off switches and instruments. The computation means can optionally include various output means. Different types of control schemes, outlined below, can be used.

[0199] A) Fuzzy Logic Control and Other Types of Control:

[0200] Fuzzy logic control as well as other types of control can equally be used in feed forward and feedback control schemes. These types of control can substantially deviate from classical P, I, D combination control in the ways the reaction dynamics are modeled and simulated to predict how to change input variables or input parameters to affect a desired outcome. Fuzzy logic control usually only requires a vague or empirical description of the reaction dynamics (in general the system dynamics) or the operating conditions of the system. Aspects and implementation considerations of fuzzy logic and other types of control are well known to a person skilled in the art.

[0201] B) Feed-Forward Control:

[0202] Feed forward control processes input parameters to influence, without monitoring, control variables and control parameters. A gasification facility can use feed forward control for a number of control parameters such as the amount of power supplied to one of the one or more plasma torches in the gas reformulating chamber (GRS). The power output of the arcs of plasma torches can be controlled in a variety of different ways, for example, by pulse modulating the electrical current which is supplied to the torch to maintain the arc, varying the distance between the electrodes, limiting the torch current, or affecting the composition, orientation or position of the plasma.

[0203] The rate of supply of additives to the gasifiers and/or the gas reformulator in a gaseous or liquid form or a pulverized form which can be sprayed or otherwise injected via nozzles, can be controlled with certain control elements in a feed forward way. Effective control of an additive's temperature or pressure, however, may require monitoring and closed loop feed back control.

[0204] C) Feed-Back Control:

[0205] In feedback control the value of a control parameter or control variable is compared to a desired value. A control signal is determined based on the deviation between the two values and provided to a control element in order to reduce the deviation. For example, when the output gas exceeds a predetermined H_2:CO ratio, a feedback control system can determine an appropriate adjustment to one of the input variables, such as increasing the amount of additive air to return the H_2:CO ratio to the desired value. The delay time to affect a change to a control parameter or control variable is sometime called loop time. The loop time, for example, to adjust the power of the plasma arc, air or steam flow rate, can amount to 30 to 60 seconds.

[0206] Feed back control may be used for all control variables and control parameters which use direct monitoring or where a model prediction is satisfactory. There are a number of control variables and control parameters of the gasifier that lend themselves towards use in a feedback control scheme. Feedback schemes can be effectively implemented in aspects of the control system for those control variables or control parameters which can be directly sensed and controlled and whose control does not, for practical purposes, depend upon other control variables or control parameters.

Modularity of the System

[0207] Modulated plants are facilities where each function block is pre-built components. This allows for the components to be built in a factory setting and then sent out to the facility site. These components (or modules) include all the equipment and controls to be functional and are tested before leaving the factory. Modules are often built with a steel frame and generally incorporate a variety of possible sections, such as: Gasifier Block, Gas Conditioning System Block, Power Block, etc. Once on-site, these modules would only need to be connected to other modules and the control system to be ready for plant's commissioning. This design allows for shorter construction time and economic savings due to reduced on-site construction costs.

[0208] There are different types of modular plants set-ups. Larger modular plants incorporate a 'backbone' piping design where most of the piping is bundled together to allow for smaller footprint. Modules can also be placed in series or parallel in an operation standpoint. Here similar tasked equipment can share the load or successively provide processing to the product stream.

[0209] One possible application of modular design in this technology is it allows more options in the gasification of multiple wastes. This technology can allow for multiple gasifiers to be used in a single high-capacity facility. This would allow the option of having each gasifier co-process wastes together or separately; the configuration can be optimized depending on the wastes.

[0210] If an expansion is required due to increasing loads, a modular design allows this technology to replace or add modules to the plant to increase its capacity, rather then building a second plant. Modules and modular plants can be relocated to other sites where they can be quickly integrated into a new location.

Function Block Combination

[0211] It is possible to combine the functions of different gasification trains (series of equipment) so that common functions can be carried out in function blocks that take in gases or material from more than one stream. The following diagrams demonstrate this concept as applied to carbonaceous feedstock gasification.

[0212] In these embodiments there are two trains shown although this set-up of combined functions between trains can occur for any number of trains and for any feedstock per train (even if one train has a combined feedstock). Once a stream has been combined one may still choose parallel handling equipment downstream; the parallel streams do not need to be of the same size even if handling the same gases.

[0213] For the following description, GCS refers to the gas conditioning system mentioned above and the numbers represent the following systems

[0214] 1. Gasifier

[0215] 2. Residue Conditioning System

[0216] 3. Gas Reformulating System

[0217] None Combined, FIG. **31**

[0218] In this embodiment there are two separate systems that can have the gas streams mixed for downstream system; like the homogenization tank or engines.

[0219] GCS Combined

[0220] In this embodiment the gases from function blocks **2** & **3** from each train are fed together into a single GCS which has been sized appropriately for the gas flow.

[0221] Function **2** Combined, FIG. **32**

[0222] In this embodiment the trains differ only in function block **1**, with all other functions being handled by the same combined train of equipment.

[0223] Function **3** Combined, FIG. **33**

[0224] In this embodiment gases from function blocks **1** go to a combined function block **3**; which is sized appropriately.

[0225] Function **2** & **3** Combined, FIG. **34**

[0226] In this embodiment gases from function blocks **1** go to a combined **2** and material from function block **1** go to a combined function block **3**; which are sized appropriately. Gases from combined function blocks **2** & **3** then travel to a combined GCS.

[0227] A worker skilled in the art will readily understand that while in the above section we have mentioned the gasification system as comprising of the function blocks **1**, **2** & **3** and the GCS, it can be further subdivided into other smaller function blocks. For example, the function block **1**, **2** & **3** could represent the drying region, volatilization region and the carbon conversion region respectively such that a single gasifier can be formed by the combination of these function blocks. A worker skilled in the art will readily appreciate that for each designation of function blocks, the trains can be combined in a larger family of schemes depending on where the combination of the trains is effected.

[0228] The embodiments of the invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

1. A gasifier for conversion of carbonaceous feedstock into gas and residue, the gasifier comprising

one or more processing chambers, two or more vertically successive processing regions being distributed within said one or more processing chambers, within each one of which a respective process selected from the group consisting of drying, volatilization and carbon conversion is at least partially favoured, said processing regions being identified by temperature ranges respectively enabling each said respective process;

one or more additive input elements associated with said processing regions for inputting additives to promote each said at least partially favoured process therein;

one or more material displacement control modules adapted to control a vertical movement of the feedstock through said processing regions to enhance each said at least partially favoured process;

one or more feedstock inputs located near a first of said processing regions;

one or more gas outputs; and

one or more residue outputs.

2. The gasifier as claimed in claim 1, wherein said processing regions are promoted by a combination of said one or more processing chambers and by a positioning of said one or more additive input elements in each of said processing chambers.

3. The gasifier as claimed in claim 1, the gasifier for use in a gasification system comprising a control system, the gasifier being configured to operate in accordance with control parameters provided by the control system determined in response to one or more sensed characteristics indicative of one or more process characteristic variations of the gasification system.

4. The gasifier as claimed in claim 3, wherein the one or more material displacement control modules are operatively coupled to the control system and at least partially controlled thereby to affect a change in said one or more sensed characteristics.

5. The gasifier as claimed in claim 4, wherein said one or more characteristics comprises one or more of a carbon content of the product gas, a heating value of the product gas, a hydrogen content of the product gas and a carbon monoxide content of the product gas, and wherein said one or more material displacement control modules are configured to adjust said vertical movement of the feedstock through said processing regions in response to a sensed variation in said one or more characteristics to affect a change in same.

6. The gasifier as claimed in claim 1, the gasifier comprising two or more vertically successive processing chambers, one or more of said two or more vertically successive processing regions being defined within each of said two or more processing chambers.

7. The gasifier as claimed in claim 1, the gasifier comprising one processing chamber, said one chamber comprising two or more additive input elements, each one of which being positioned and operated so to promote a respective one of said two or more vertically successive processing regions.

8. The gasifier as claimed in claim 1, wherein said gas output is in fluid communication with a gas reformulating system for reformulating at least some of the gas output from the gasifier.

9. The gasifier as claimed in claim 1, wherein said gas output is connected to a gas reformulating system via piping for reformulating at least some of the gas output from the gasifier.

10. The gasifier as claimed in claim 1, wherein said gas output is in fluid communication with a gas storage tank for storing at least some of the gas output from the gasifier.

11. The gasifier as claimed in claim 1, wherein said residue output is in operative communication with a residue processing system for further processing of the residue.

12. The gasifier as claimed in claim 1, wherein said residue comprises a partially processed carbonaceous feedstock and wherein said residue output is in operative communication with a second gasifier for conversion of said partially processed carbonaceous feedstock.

13. The gasifier as claimed in claim 12, wherein said second gasifier is a vertically oriented gasifier as claimed in claim 1.

14. The gasifier as claimed in claim 13, wherein said second gasifier is a laterally oriented gasifier.

15. The gasifier as claimed in claim 1, the feedstock being partially processed feedstock provided from an upstream gasifier and wherein said feedstock input is in operative communication with a residue output of said upstream gasifier for further processing of said partially processed carbonaceous feedstock.

16. The gasifier as claimed in claim 1, wherein said material displacement control module is actively controlled for facilitating exit of residue from a final one of said processing regions, thereby indirectly controlling a downward movement of reactant material through others of said processing regions to said final one thereof.

17. The gasifier as claimed in claim 1, wherein said material displacement control module comprises one or more of a rotating arm, a rotating wheel, a rotating paddle, a rotating grate, a moving shelf, a pusher ram, an extractor screw, and a conveyor.

18. The gasifier as claimed in claim 1, wherein the gasifier is heated using separate, independently controlled means for heating said processing regions.

19. The gasifier as claimed in claim 18, wherein said means for heating comprises one or more of said additive input elements for injection of pre-heated air.

20. The gasifier as claimed in claim 1, wherein mechanical means are inserted into said processing chambers and adapted to mix the carbonaceous feedstock and said additive inputs.

21. The gasifier as claimed in claim 1, wherein the feedstock input is in operative communication with a controllable feedstock input system.

22. The gasifier as claimed in claim 21, wherein said controllable feedstock input system is in operative communication with a feedstock pre-processing system.

23. The gasifier as claimed in claim 1, wherein said one or more processing chambers are chosen from a group comprising fixed bed processing chambers, gravity-induced vertical processing chambers, mechanically-assisted flow processing chambers, fluidised bed processing chambers and entrained flow processing chambers.

24. A vertically oriented gasifier for conversion of carbonaceous feedstock into gas and residue, the gasifier comprising:

one or more processing chambers, each one of which comprising one or more additive input elements for input of additives therein, wherein combination of said one or more processing chambers and a positioning of said one or more additive input elements thereof promoting creation of two or more vertically successive processing regions within the gasifier within each one of which a respective process is at least partially favoured, said processing regions being identified by temperature ranges respectively enabling each said respective process;

one or more feedstock inputs proximal to a first of said processing regions;

one or more material displacement control modules adapted to control a vertical movement of the feedstock through said processing regions to enhance each said at least partially favoured process;

one or more gas outputs; and

one or more residue outputs.

25. A method for converting a carbonaceous feedstock into gas and residue comprising the steps of:

providing a gasifier;

creating two or more vertically successive processing regions within said gasifier, within each one of which a respective process selected from the group consisting of drying, volatilization and carbon conversion is at least partially favoured, said processing regions being identified by temperature ranges respectively enabling each said respective process,

inputting additives within the gasifier to promote each said at least partially favoured process;

controlling a downward movement of the feedstock through said processing regions thereby optimizing each said at least partially favoured process; and

outputting the gas and residue from the gasifier.

26. The method as claimed in claim 25, said gasifier comprising two or more vertically successive processing chambers, one or more of said two or more vertically successive processing regions being created within each of said two or more processing chambers.

27. The method as claimed in claim 25, said gasifier comprising one processing chamber, said inputting additives step comprising inputting additives via two or more additive input elements, each one of which being positioned and operated so to promote a respective one of said two or more vertically successive processing regions.

* * * * *