US 20110289845A1

(19) United States
(12) Patent Application Publication
Davis et al.
(10) Pub. No.: US 2011/0289845 A1
(43) Pub. Date: Dec. 1, 2011

(54) METHOD FOR CONTROLLING SYNGAS PRODUCTION IN A SYSTEM WITH MULTIPLE FEED MATERIALS USING A MOLTEN METAL BATH

(75) Inventors: **William H. Davis**, Winchester, MA (US); **Irving B. Morrow, JR.**, Harvard, MA (US); **Kevin Donahue**, Harvard, MA (US); **Igor Polovtsev**, Forest Hill, MD (US)

(73) Assignee: **Ze-Gen, Inc.**, Boston, MA (US)

(21) Appl. No.: **12/899,809**

(22) Filed: **Oct. 7, 2010**

Related U.S. Application Data

(63) Continuation-in-part of application No. 11/400,973, filed on Apr. 10, 2006, now abandoned, Continuation-in-part of application No. 12/105,325, filed on Apr. 18, 2008.

(60) Provisional application No. 60/670,332, filed on Apr. 12, 2005, provisional application No. 60/912,440, filed on Apr. 18, 2007.

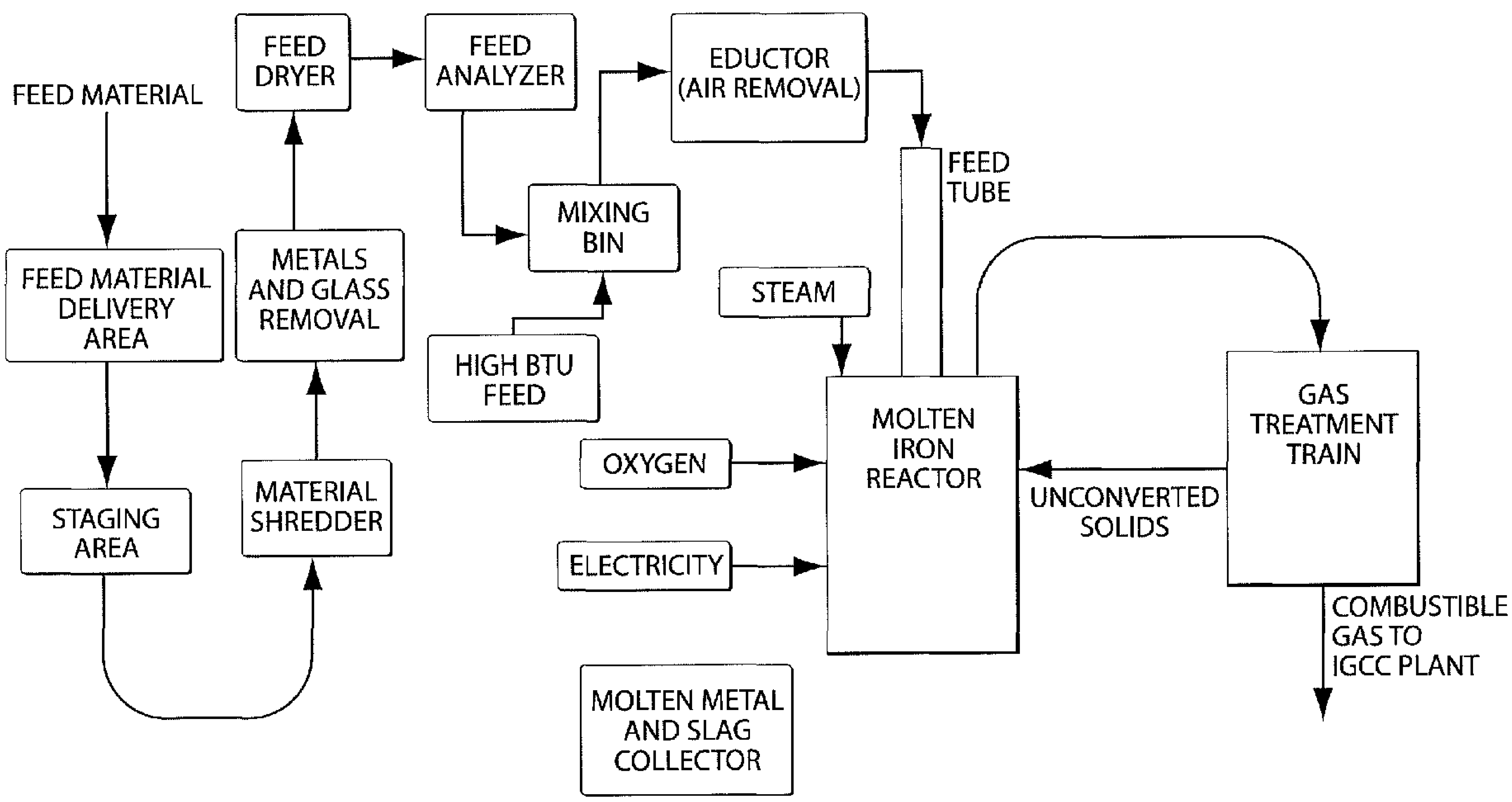
Publication Classification

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

(52) U.S. Cl. .... 48/197 R

(57) **ABSTRACT**

Processes and apparatus for treating organic and inorganic materials in a metal bath contained in a high temperature reactor to produce synthesis gas are provided. Two or more feed materials that possess differing syngas generation potentials are mixed in a mixer and fed as a composite feed stream into a gasifier to produce syngas. The feed materials are prepared and analyzed for heat value prior to injection and the composition of materials in and exiting the reactor are monitored. By controlling the feed rate of the mixture into the gasifier as well as the feed rates of one or more of the individual feed materials into the mixer, the syngas is produced at a target production rate, with target energy content (BTU). Based upon the results of the analysis and monitoring, oxygen, steam, and/or other feed materials are also injected into the reactor, to control processing and synthesis gas quality. Potential feed materials include, but are not limited to, construction and demolition (C&D) debris, municipal solid waste (MSW), other sewage-related solids, waste tires, and other substances that contain varying levels of organic compounds capable of producing a syngas.



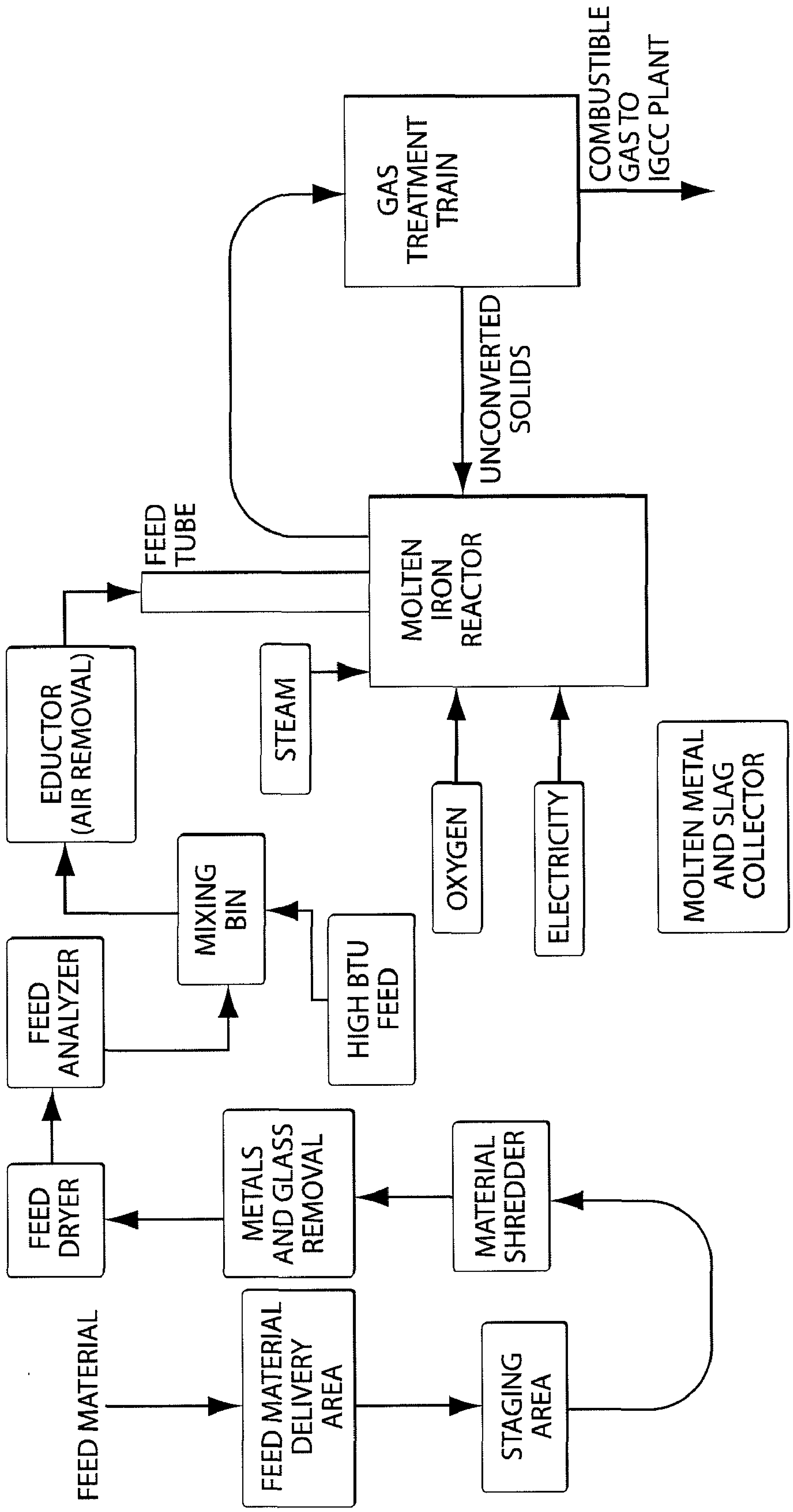

FEED MATERIAL
FEED MATERIAL DELIVERY AREA
STAGING AREA
MATERIAL SHREDDER
METALS AND GLASS REMOVAL
FEED DRYER
FEED ANALYZER
MIXING BIN
HIGH BTU FEED
EDUCTOR (AIR REMOVAL)
FEED TUBE
STEAM
OXYGEN
ELECTRICITY
MOLTEN IRON REACTOR
MOLTEN METAL AND SLAG COLLECTOR
UNCONVERTED SOLIDS
GAS TREATMENT TRAIN
COMBUSTIBLE GAS TO IGCC PLANT

Fig. 1

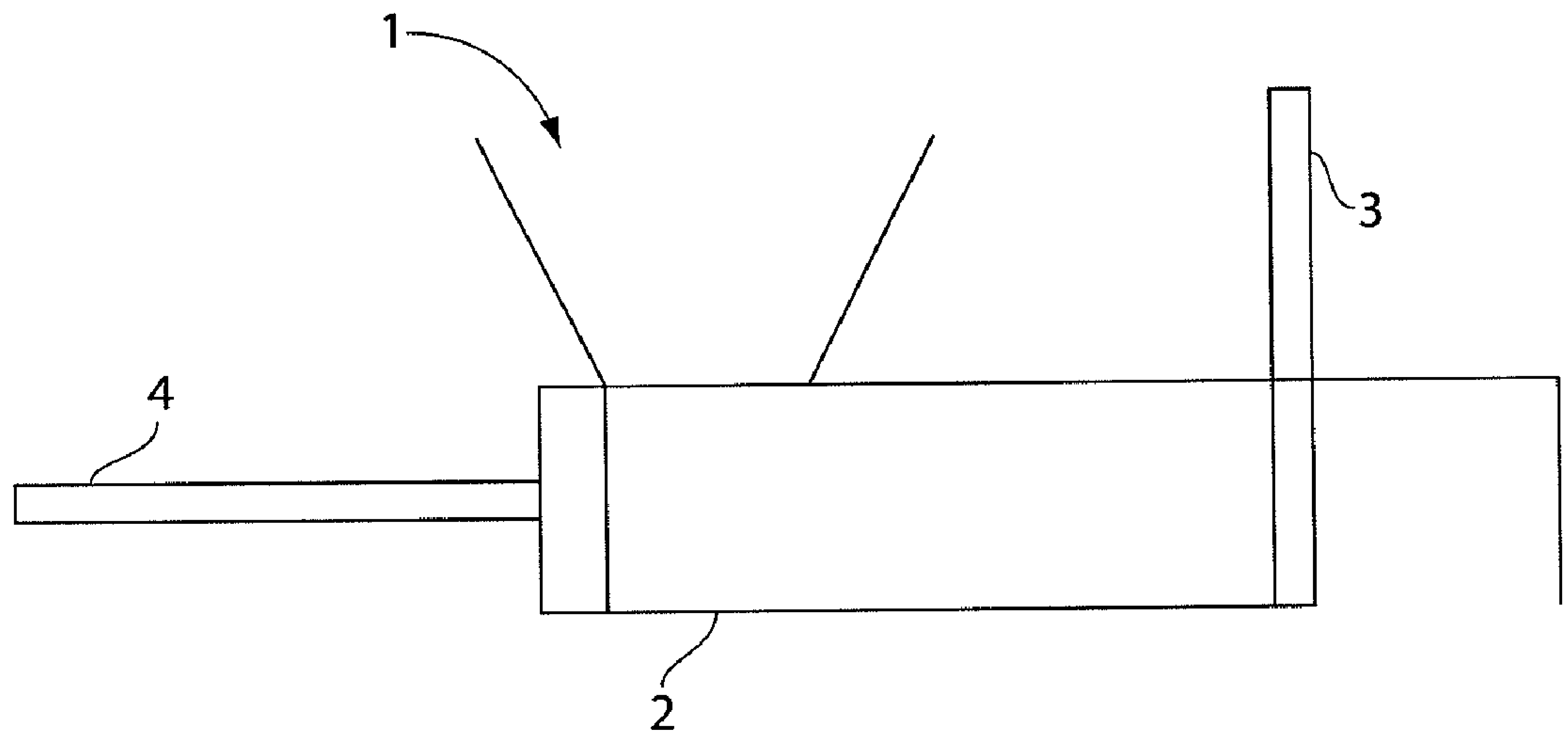


Fig. 2

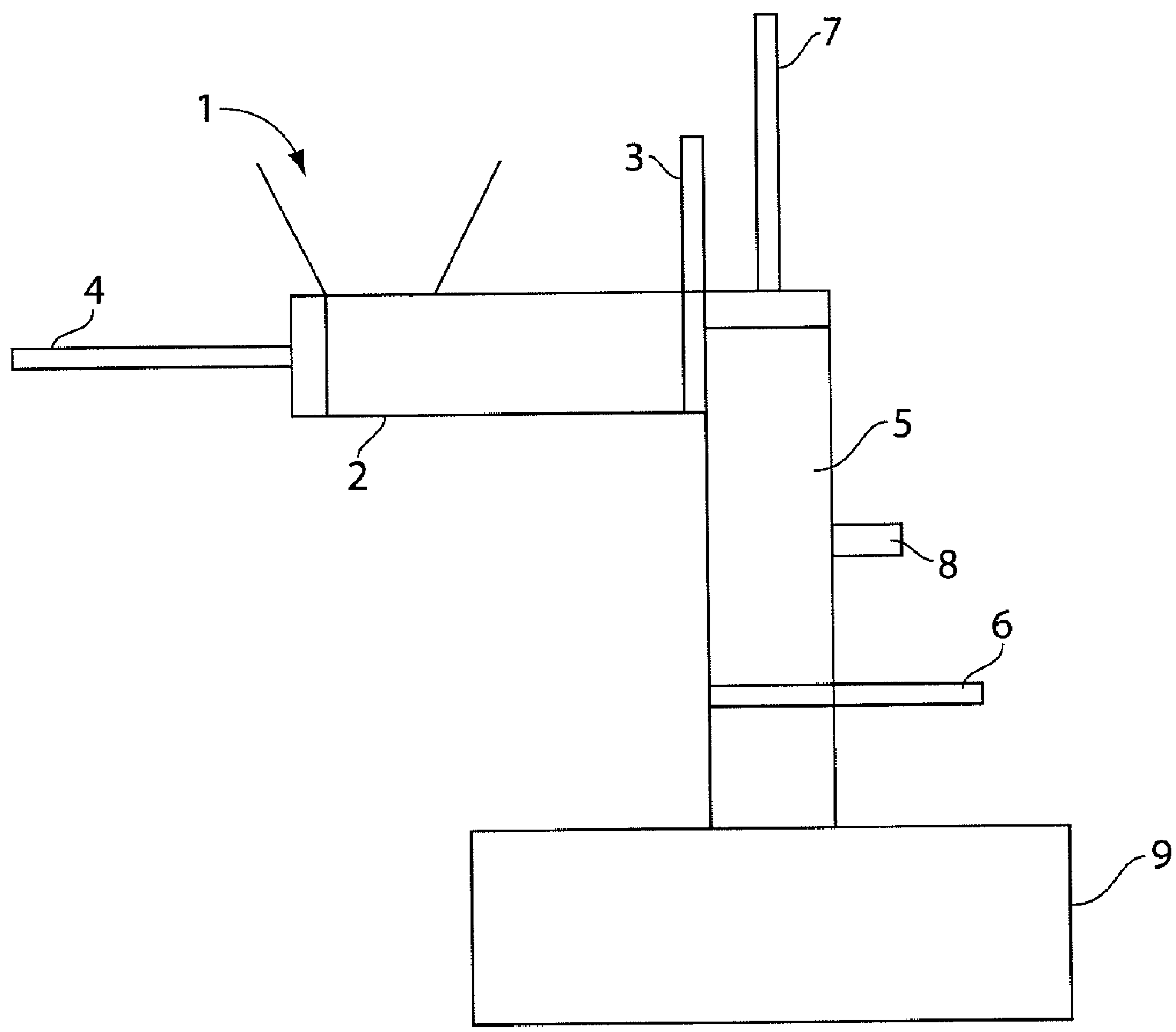


Fig. 3

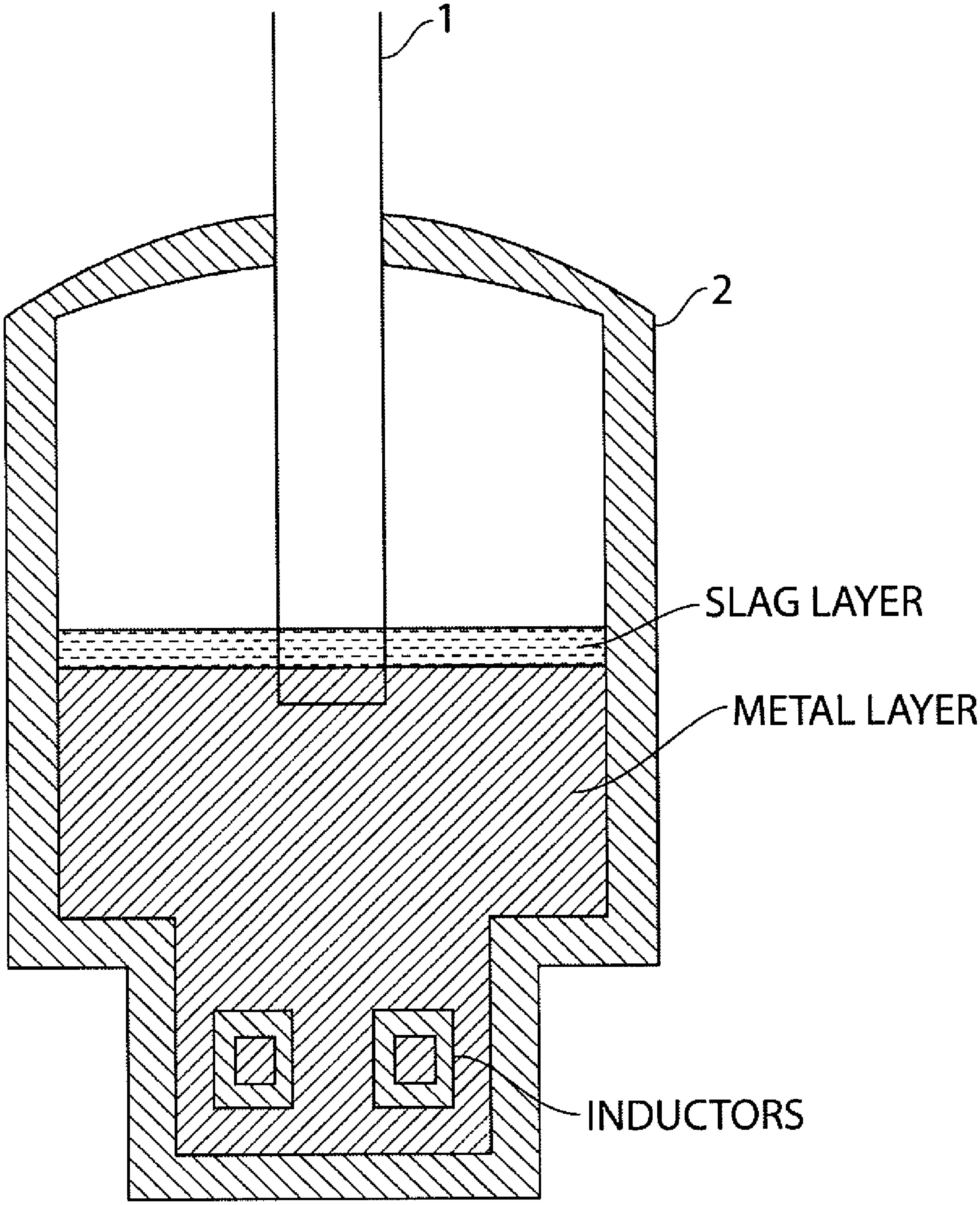


Fig. 4

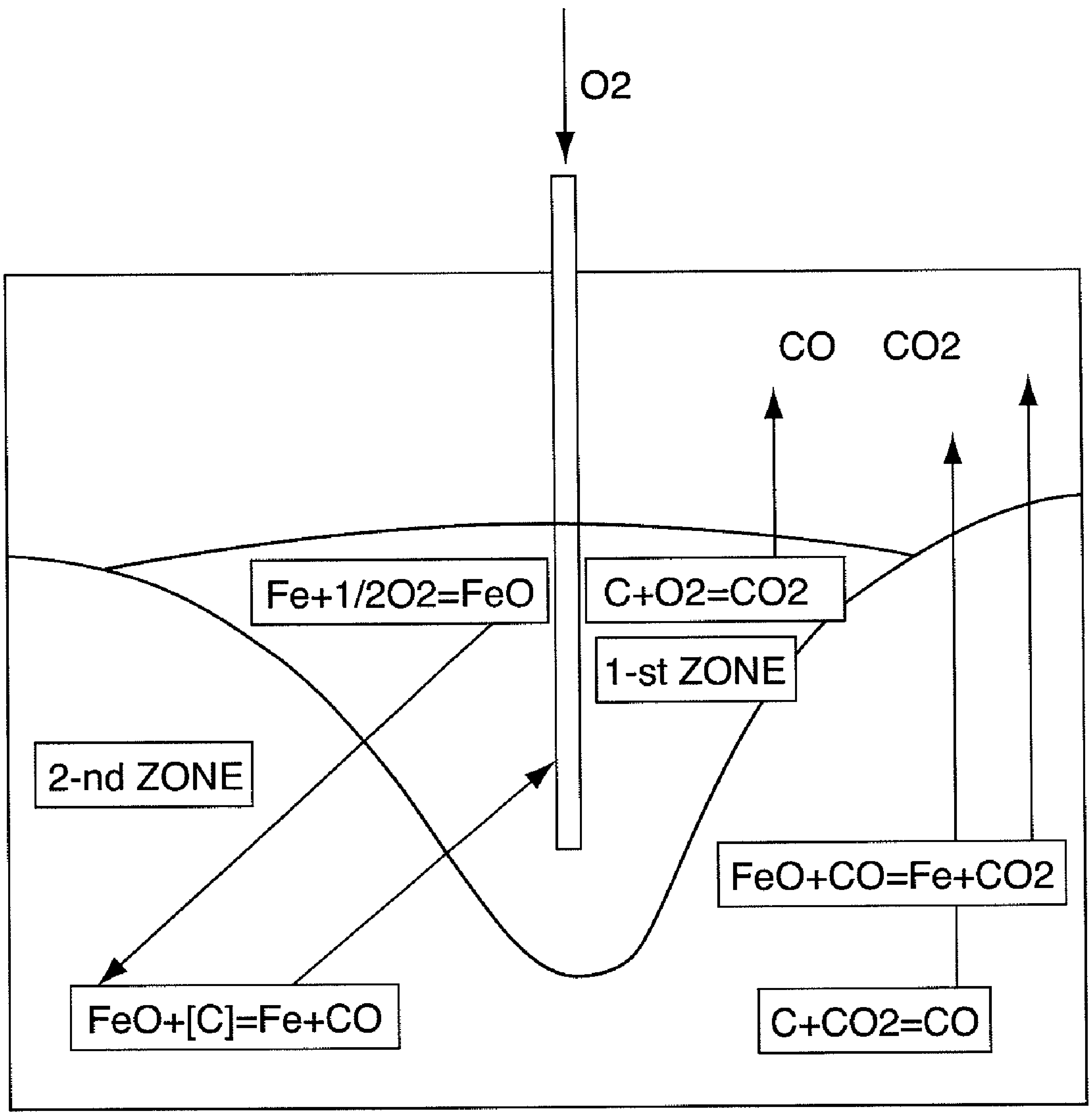

O2
CO
CO2
Fe+1/2O2=FeO
C+O2=CO2
1-st ZONE
2-nd ZONE
FeO+CO=Fe+CO2
FeO+[C]=Fe+CO
C+CO2=CO

Fig. 5

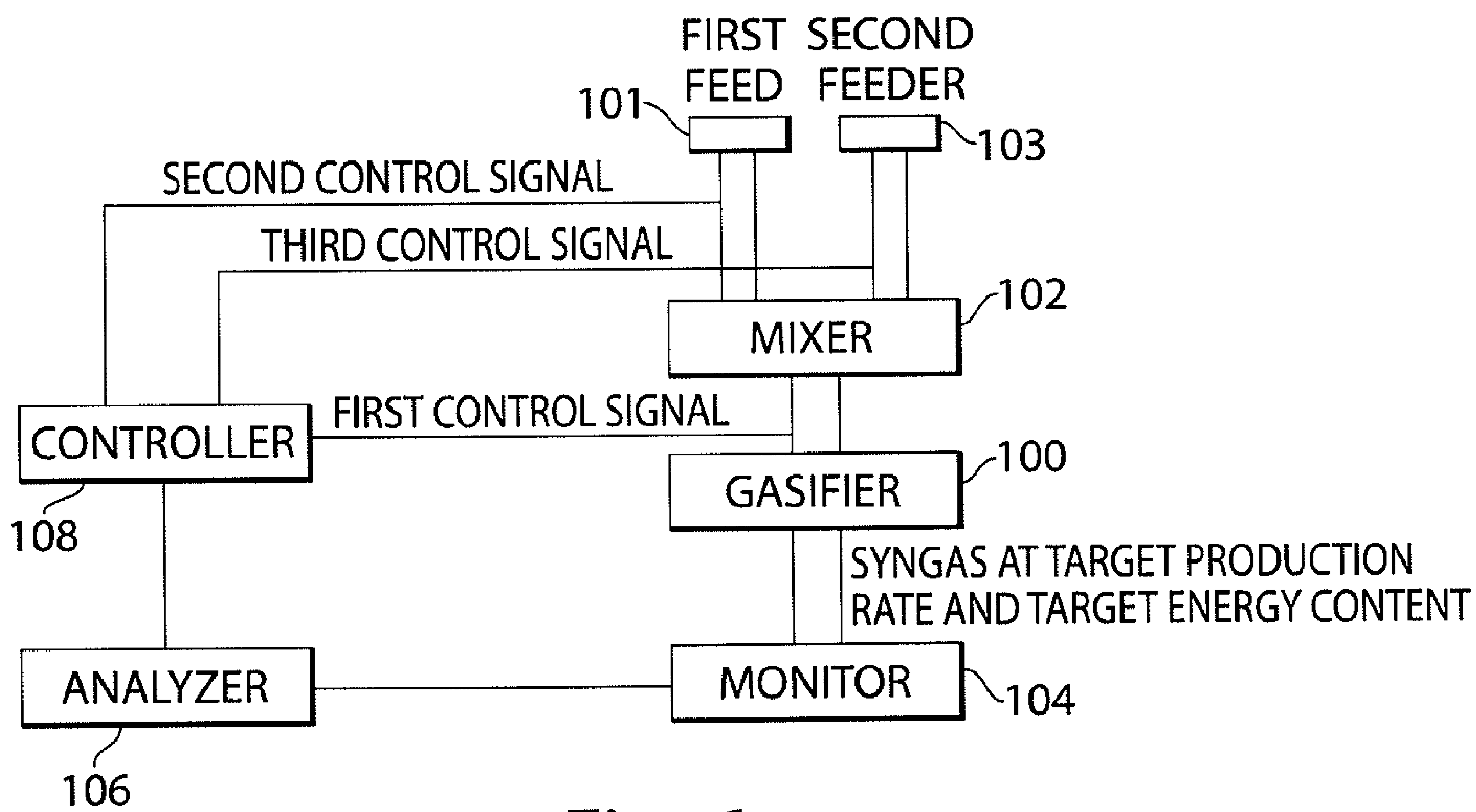

FIRST FEED
SECOND FEEDER
101
103
SECOND CONTROL SIGNAL
THIRD CONTROL SIGNAL
MIXER
102
CONTROLLER
FIRST CONTROL SIGNAL
GASIFIER
100
108
SYNGAS AT TARGET PRODUCTION RATE AND TARGET ENERGY CONTENT
ANALYZER
MONITOR
104
106

Fig. 6

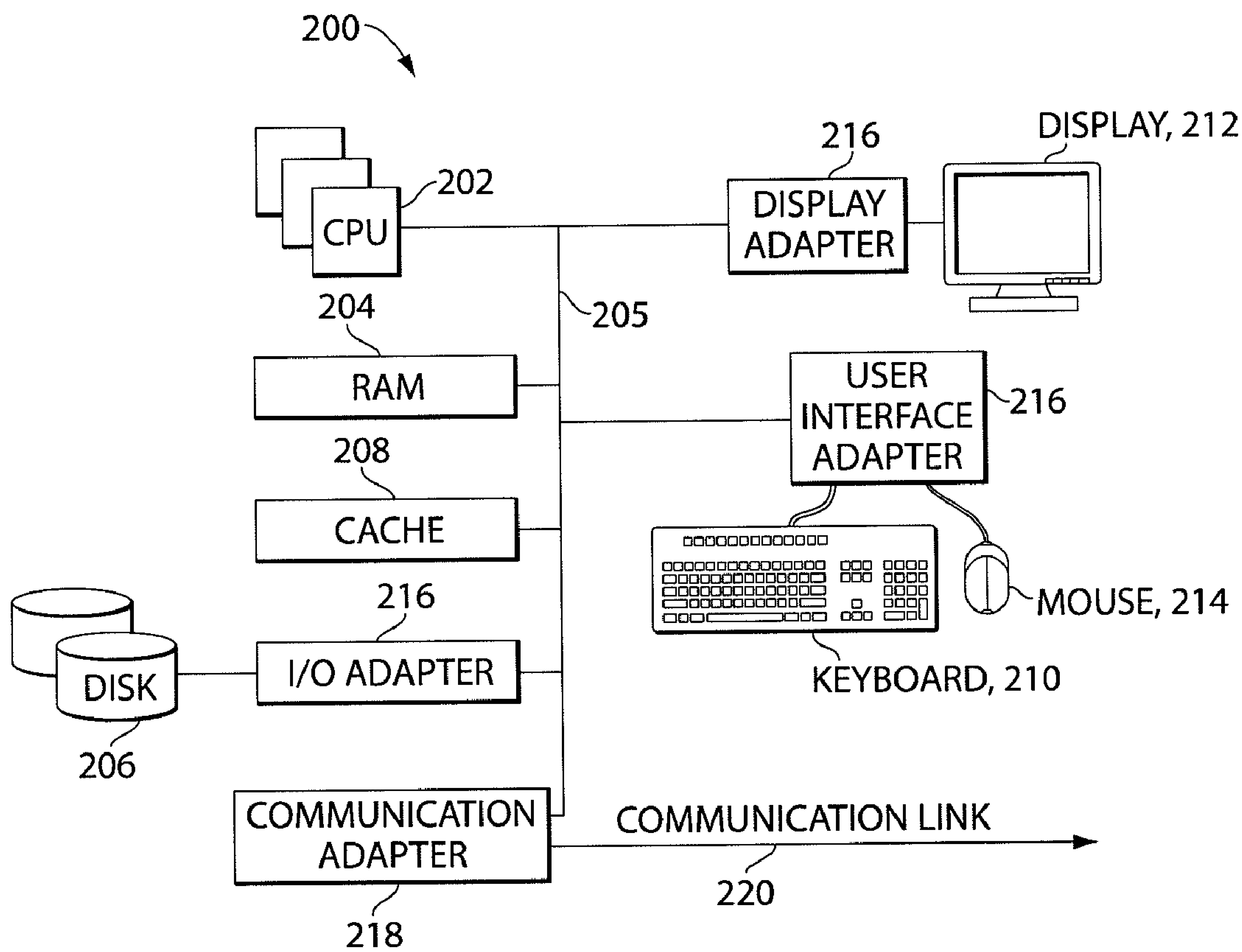

200
CPU
202
216
DISPLAY ADAPTER
DISPLAY, 212
204
205
RAM
USER INTERFACE ADAPTER
216
208
CACHE
MOUSE, 214
216
DISK
I/O ADAPTER
KEYBOARD, 210
206
COMMUNICATION ADAPTER
COMMUNICATION LINK
220
218

Fig. 7

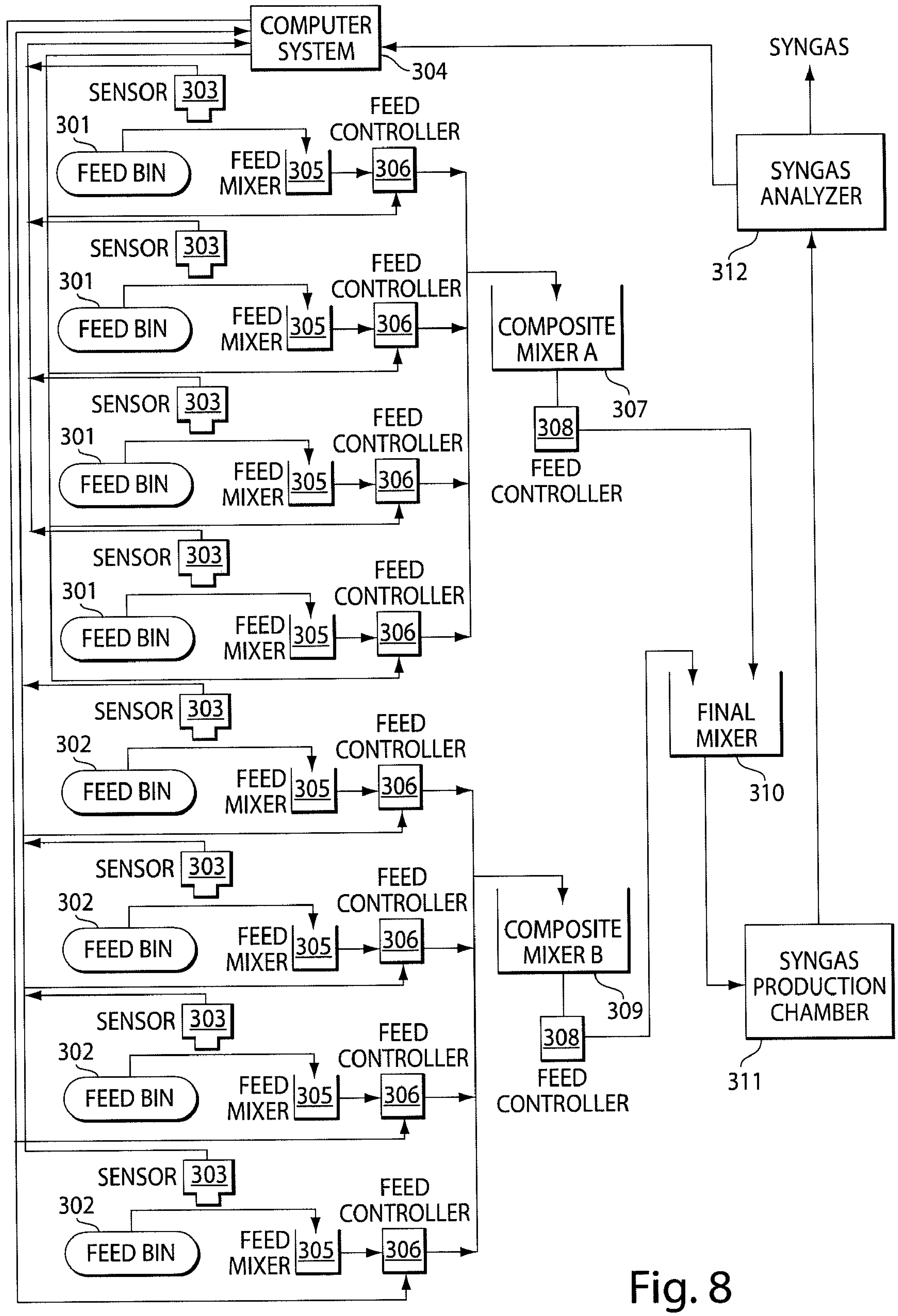

COMPUTER SYSTEM
304
SYNGAS
SENSOR 303
301
FEED BIN
FEED MIXER 305
FEED CONTROLLER 306
SYNGAS ANALYZER
312
COMPOSITE MIXER A
307
308
FEED CONTROLLER
302
FINAL MIXER
310
COMPOSITE MIXER B
309
SYNGAS PRODUCTION CHAMBER
311

Fig. 8

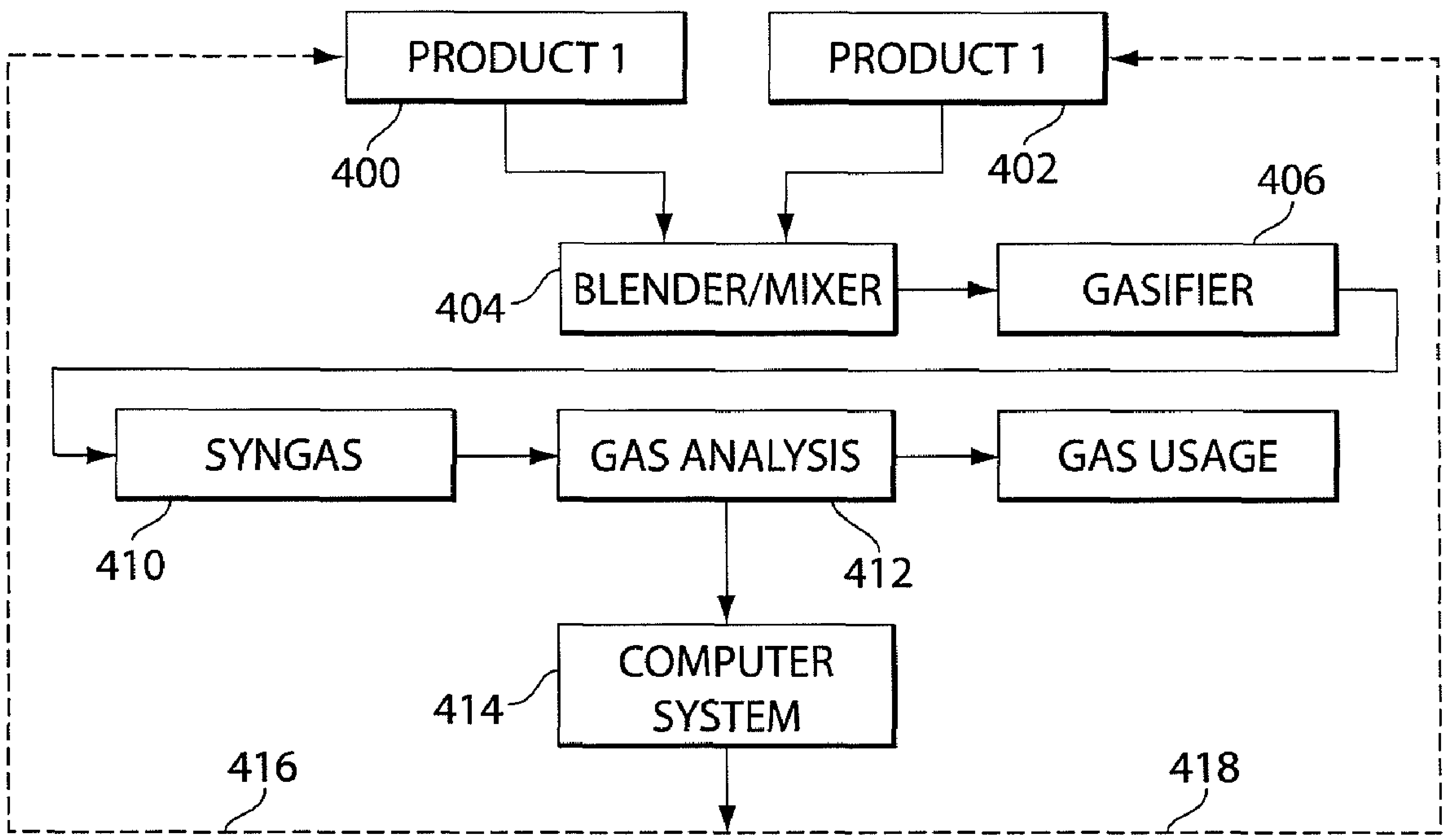

PRODUCT 1
PRODUCT 1
400
402
406
BLENDER/MIXER
GASIFIER
404
SYNGAS
GAS ANALYSIS
GAS USAGE
410
412
COMPUTER SYSTEM
414
416
418

Fig. 9

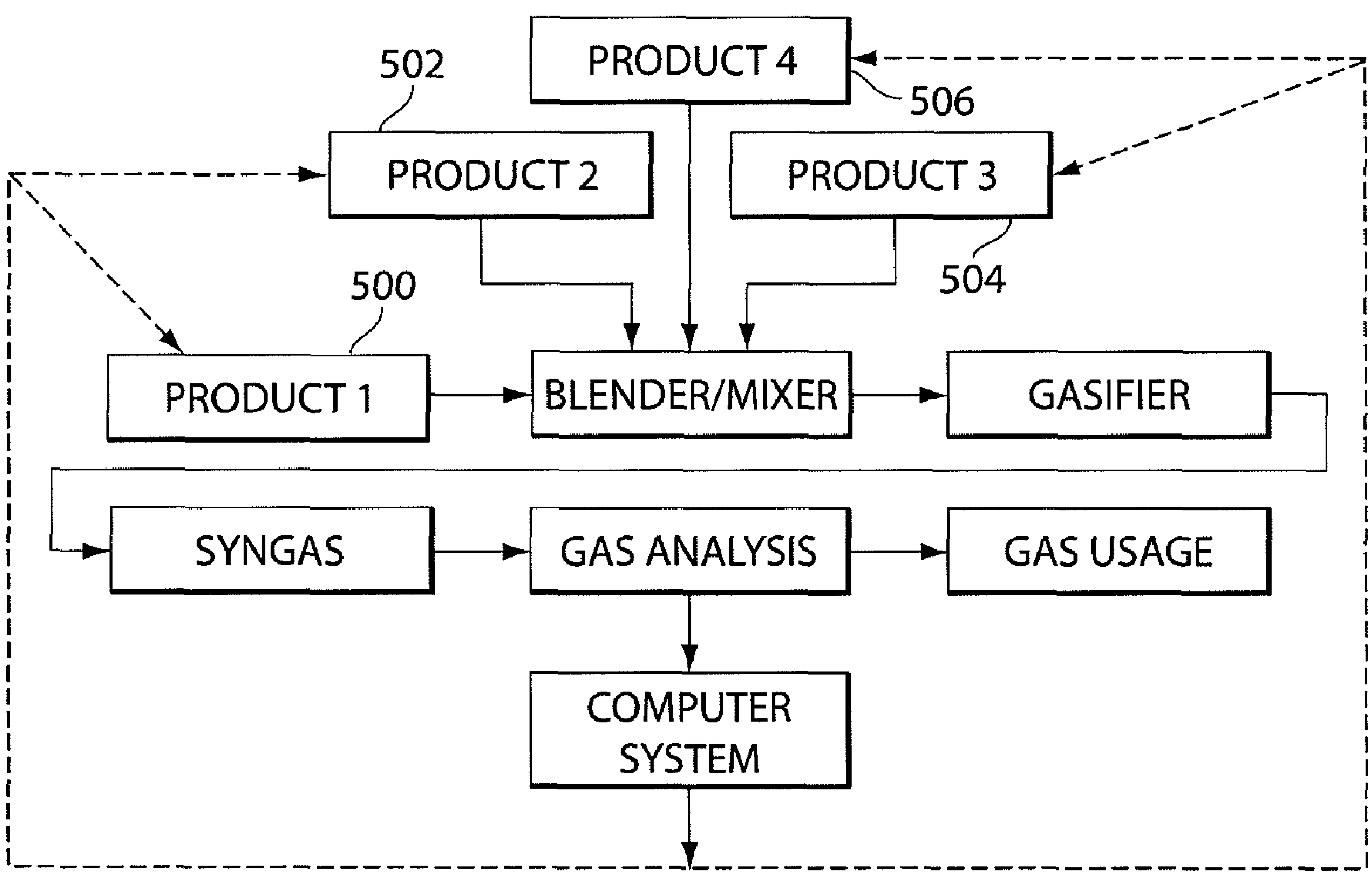

PRODUCT 4
502
506
PRODUCT 2
PRODUCT 3
500
504
PRODUCT 1
BLENDER/MIXER
GASIFIER
SYNGAS
GAS ANALYSIS
GAS USAGE
COMPUTER SYSTEM

Fig. 10

METHOD FOR CONTROLLING SYNGAS PRODUCTION IN A SYSTEM WITH MULTIPLE FEED MATERIALS USING A MOLTEN METAL BATH

RELATED APPLICATIONS

[0001] This application is a continuation-in-part of U.S. patent application Ser. No. 12/105,325, filed Apr. 18, 2008, entitled "Method for Controlling Syngas Production in a System with Multiple Feed Materials," by Davis, et al., which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/912,440, filed Apr. 18, 2007, entitled "Method for Controlling Syngas Production in a System with Multiple Feed Materials," by Davis, et al. This application is also a continuation-in-part of U.S. patent application Ser. No. 11/400,973, filed Apr. 10, 2006, entitled "Process and Apparatus using a Molten Metal Bath," by Davis, et al., which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/670,332, filed Apr. 12, 2005, entitled "Process and Apparatus using a Molten Metal Bath," by Davis, et al. Each of these is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Technical Field

[0003] The present invention relates generally to syngas production methods.

[0004] 2. Background of the Related Art

[0005] Organic and inorganic materials can be converted into vitrified material and a synthesis gas mixture of CO and H_2 (commonly referred to as "syngas") by various means. It would be desirable to convert such materials into higher value, beneficially usable products (e.g., conversion of large amounts of municipal solid waste into relatively small volumes of unleachable vitreous material and metals, and large volumes of syngas containing significant BTU value).

[0006] In the past, attempts have been made to convert wastes and other organic materials into syngas. Such processes include the steam conversion of organic material, which requires a substantial energy input. Other processes involved the use of metal baths or the use of plasma technologies. One of the greatest challenges in gasifying such feed materials is the feeds' unpredictable nature (e.g., the feed materials' chemical and physical characteristics could change dramatically in a short period of time).

[0007] It is known in the prior art to provide gasification systems that convert municipal solid waste (MSW) and construction and demolition waste (C&D) into clean energy. As described in U.S. Patent Application Publication No. 2006/0228294, which is representative, these systems may comprise a refractory, induction furnace that receives the feed material into a molten metal bath, wherein a mix of organic and non-organic material is treated resulting in metal recovery and efficient production of synthesis gas (syngas). The syngas can be used to fuel a combined-cycle generator to provide municipalities with clean, renewable electricity.

[0008] Though many of those attempts appear to have been technically possible and/or may have been successful in pilot scale demonstrations, these technologies did not allow for appropriate scaling or commercialization of the process because of the difficulty is processing the material in an economical manner, reliability of operation, controlling temperature and other key process variables, such as oxygen and steam input, etc. It would be highly desirable to have a commercially viable method for the conversion of large volumes (e.g., tons per hour) of organic and inorganic materials into synthesis gas of sufficient BTU value for commercial use and vitreous material which is useable (or at least environmentally benign)

[0009] One of the technical objectives that must be reached to ensure commercial success of the gasification technology is to achieve a high efficiency of synthesis gas generation from the processed waste streams.

BRIEF SUMMARY OF THE INVENTION

[0010] The present invention provides methods and apparatus for the conversion of feed materials containing organic and inorganic components in a refractory lined vessel having one or more inlets and outlets, and partially filled with molten metal and vitreous material, to provide for production of syngas. The syngas is formed by the partial oxidation of the organic components of the feed materials and recovery of the vitreous material and metals from the inorganic components of feed materials. The method includes (1) providing one or more feed materials, from which air has been extracted and analyzing the feed materials for heat value; (2) injecting the feed materials directly into the molten metal; (3) monitoring the composition of the molten metal, the vitreous material, the synthesis gas and the reactor temperature; (4) injecting oxygen, steam and/or co-feeding one or more additional feed materials of higher heat value than the analyzed feed materials, with the amounts injected being based upon the analysis and monitoring results; and (5) continuously removing synthesis gas and periodically removing metal and/or vitreous material from the reactor. An overall process diagram is presented on FIG. **1** and is more fully discussed hereinafter.

[0011] Two or more feed materials that possess differing syngas generation potentials are mixed in a mixer and fed as a composite feed stream into a gasifier to produce syngas. By controlling the feed rate of the mixture into the gasifier as well as the feed rates of one or more of the individual feed materials into the mixer, the syngas is produced at a target production rate, with target energy content (BTU). Potential feed materials include, but are not limited to, construction and demolition (C&D) debris, municipal solid waste (MSW), other sewage-related solids, waste tires, and other substances that contain varying levels of organic compounds capable of producing a syngas.

[0012] In a representative embodiment, two or more feed materials, each preferably having a different BTU value, are mixed to create a blend, which is then fed to a gasifier. The mixture of materials having various BTU content produces a blend having a final BTU content value. Desired operating conditions are a target production rate, which typically represents a mass flow rate exiting the gasifier (or, more generally, the gasification stage), at a target energy content. According to the process, a feed rate of the mixture into the gasifier is sped up or slowed down to produce a constant or substantially constant mass flow of syngas (i.e. the target production rate), while the feed rate(s) of one or more of the individual feed materials are adjusted as necessary to maintain the target energy content. The feed rates are adjusted using one or more control signals. The control signals are generated by a controller, which derives the values of these signals by analyzing data received from components that monitor the syngas. In particular, together with temperature measurements, syngas mass flow measurements are taken in exhaust ducting from the gasifier, e.g., by means of a pitot tube or other velocity or flow measuring devices. This real-time data is then analyzed, for example, for carbon monoxide, hydrogen and/or total hydrocarbons levels, to determine the BTU content of the syngas output from the gasifier. Using the data, a controller adjusts the material feed rate(s) accordingly to attempt to maintain the syngas target production rate at the target energy content.

[0013] The invention also provides an apparatus for the processing of organic and inorganic feed material comprising (1) a refractory lined vessel having one of more inlets and one or more outlets, and suitable for the containment of molten metal; (2) feed material preparation units (such as dryer and shredders); (3) analyzers for continuously analyzing the feed material prior to injection into the vessel; (4) injectors for injecting air-extracted feed material into the vessel; (5) monitors for the composition of the metal, the vitreous material and the synthesis gas; (6) injectors for injecting steam into the vessel at a predetermined level above which the molten metal would be contained; (7) oxygen and co-feeds injectors for injecting these materials into the vessel at a predetermined level below which the molten metal would be contained; (8) controllers for regulating the amount of steam, oxygen, and co-feed injection, responsive to the results of said analyzers and monitors; and (9) outlets in the vessel for continuously removing syngas.

[0014] The foregoing has outlined some of the more pertinent features of the invention. These features should be construed to be merely illustrative. Many other beneficial results can be attained by applying the disclosed invention in a different manner or by modifying the invention as will be described.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0016] FIG. **1** is a flow chart of a process of the present invention for processing a waste stream, including preferred optional features of the invention;

[0017] FIG. **2** is a schematic illustration of a feeding arrangement in one embodiment of the present invention;

[0018] FIG. **3** is a schematic illustration of a feeding arrangement in another embodiment of the present invention;

[0019] FIG. **4** is a schematic illustration of a product feed arrangement into the reactor for use in the present invention and a preferred reactor configuration;

[0020] FIG. **5** is an illustration of the chemical zones in the reactor;

[0021] FIG. **6** illustrates a process flow to provide syngas at a target production rate having a target energy content according to the subject matter herein;

[0022] FIG. **7** is data processing system for use in a control system that implements the process flow shown in FIG. **6**;

[0023] FIG. **8** is a representative mixing system in which the method described herein is implemented;

[0024] FIG. **9** is an embodiment where a single feedstock is added to a primary feedstock (e.g., C&D waste) to produce and maintain syngas at a target production rate and BTU value; and

[0025] FIG. **10** is another embodiment where multiple feedstocks are added to a primary feedstock to produce and maintain the syngas at the target production rate and BTU value.

DETAILED DESCRIPTION OF THE INVENTION

[0026] Gasification of waste is a well-developed technology. According to the disclosure herein, an optimization is provided whereby two or more feed materials, preferably of varying energy (e.g., BTU) content values, are blended (mixed) and supplied to the gasifier. The syngas output from the gasifier preferably has associated therewith a "target" (or desired) production rate at a target energy content. This is desirable where, for example, the syngas is being used to operate a gas turbine or the like. Thus, for example, production rate typically is a fixed number of tons per hour (or some other temporal metric), and target energy content is some desired BTU content value at that target production rate. Using two or more feed materials, preferably of different BTU values, a mixture or blend is created in advance of the gasification stage.

[0027] The present invention provides for the conversion of one or more feed materials containing organic and inorganic components in a refractory lined vessel (as described below) which, in operation, is partially filled with molten metal and vitreous material. The feed materials are analyzed and selected to provide for optimal production of syngas formed by the partial oxidation of the organic components of the feed materials and recovery of vitreous material and metals from the inorganic components of feed materials.

[0028] In particular, preferably the materials having various BTU content values are blended together for a final BTU content value. The target production rate and target energy content of the syngas are the desired operating conditions. According to the described process, the feed rate of the mixture into the gasifier is sped up or slowed down to produce a constant or substantially constant mass flow of syngas; in addition, and as necessary, the feed rate(s) of one or more of the individual feed materials (into the mixing unit) are adjusted to maintain (or attempt to maintain) the target energy content. Preferably, together with temperature measurements, syngas mass flow measurements are taken in exhaust ducting from the gasifier, e.g., by means of a pitot tube or other velocity or flow measuring devices, to calculate real-time data values. This data is then analyzed, for example, for carbon monoxide, hydrogen and total hydrocarbons levels, to determine the BTU content of the syngas. Using the data, a controller adjusts the feed rates accordingly.

[0029] As used herein, the phrase "target production rate" should not be construed as being limited to a single value, as a "rate" may include a range of acceptable values (typically, the mass flow rate). Also, the word "maintain" in the phrase "maintain production rate" does not require that the associated production rate or energy content be exactly equal to a given value. Also, the word "mixed" or "mixing" may be considered synonymous with "blend" or "blending."

[0030] FIG. **6** illustrates this basic process flow. A gasifier **100** receives a feed mixture from a mixer **102** using a feeder. The mixer **102** is supplied with at least a first feed material **101** and a second feed material **103**. First feed material is fed to the mixer **102** at a fixed or adjustable rate using a feeder; second feed material is fed to the mixer **102** at a fixed or adjustable rate using a feeder. The output of gasifier **100** is syngas having a target production rate with target energy content. Monitor **104** in exhaust ducting (or other structure) measures syngas mass flow rate and analyzer **106** analyzes the CO, H_2 and other hydrocarbons to determine the energy (e.g., BTU) content of the syngas. The resulting data (perhaps with other data, such as temperature readings) is supplied to controller **108**, which may be implemented in any convenient manner such as a computer, programmable logic controller (PLC), a combination thereof, or the like. The controller **108** takes the data and compares it to target production rate and target energy content. Controller **108** then generates a first control signal to adjust the feed rate of the material into the gasifier as necessary to reach and then maintain (or attempt to maintain) constant the target production rate. Controller **108** also generates second and/or third control signals and as necessary to adjust the feed rate(s) of one or both of the feed materials into the mixer **102**; this operation maintains (or attempts to maintain) constant the target energy content. This control operation may be initiated at any convenient time, e.g., after a steady state of the process is achieved.

[0031] The above-described operation ensures a consistent BTU value of syngas production.

[0032] Among the suitable feed materials are waste materials such as municipal solid waste (MSW), refuse derived fuels (RDF), including RDF based upon MSW, construction and demolition wastes (C&D), wastewater sludge, scrap tires, plastic wastes, medical waste, waste oils, as well as other non-waste materials such as coal or petroleum coke. Most preferred are MSW, C&D and other materials, which due to their carbon, hydrogen and oxygen content, can be efficiently converted to syngas by the practice of this invention. The advantages of the present invention are most relevant to the processing of solid feed materials, although non-solid material (e.g., semi-solid mixtures and liquid feeds) may also be suitably processed.

[0033] The present invention is particularly well suited to the processing of MSW, C&D and RDF. Prior approaches could not effectively deal with the challenges posed by the highly variable compositional makeup of MSW, particularly the inconsistency of its BTU content. For example the BTU of MSW and C&D can typically range from about 7500 BTU/cu ft (for streams containing high percentages of wood, paper and plastics) to as low as about 3000 BTU/cu ft for streams containing low percentages of the foregoing high BTU components and/or high percentages of low BTU material such as rock, glass, water and metal).

[0034] The present invention effectively deals with this BTU variability. The processes and apparatus herein (i) analyze the feed materials for heat value (e.g., preferably continuously using neutron beam-induced gamma radiation spectroscopy or by taking frequent samples and analyzing their heat value by calorimeter or other conventional methods) of incoming stream before introducing it into the reactor, (ii) monitor (preferably continuously or by periodic sampling) the composition of the molten metal for carbon content and metals; (iii) monitor (preferably continuously) the composition of the gaseous stream in the headspace of the reactor or in the off-gas stream (e.g., for H_2, H_2O, H_2S, CO_2 and carbon monoxide content by use of one or more gas analyzers and the temperature of such stream) and (iv) based upon the analysis and monitoring results, oxygen and/or co-feeds (other feedstocks such as shredded tires, petroleum coke etc. of known and/or higher BTU value) are injected (preferably dynamically blending), in order to achieve and maintain the desired BTU value in the off-gas stream.

[0035] Many of these feed materials (e.g., MSW) have highly variable composition and physical form. In accordance with this invention, prior to injection into the reactor, the feed materials are prepared and analyzed for their heat values.

[0036] Feed material preparation includes the extracting of air from the feed material. The presence of air, which is 79% nitrogen, would result in a dilution of the syngas concentration and reduce its BTU value. In the practice of this invention, BTU value of the gas generated will preferably be in the range of 280-450 BTU/ft^3. The feeder should ensure that essentially all of air contained in the waste is extracted. The most common concern in the material feeds is the presence of air, with the concern being based upon the nitrogen and other inert components which are present, not the oxygen component. It is preferred than the air or other inert gas content of the feed be less than about 1% of the weight of the feed, most preferably below about 0.5%. Although higher percentages will undesirably result in dilution of the syngas, somewhat higher percentages may be acceptable depending on the intended use of the syngas.

[0037] Depending on the nature of the feed material, the process of this invention will also typically include sizing, separating and drying steps to prepare the feed prior to injection. For example, for MSW, the feed material would typically go through:

[0038] 1. a sizing process (e.g., reduced in size to less than 1" to 2" to simplify any later extraction of inorganic materials and facilitate injection),

[0039] 2. a separation process (e.g., to separate out ferrous and non ferrous metals, concrete and glass.

[0040] 3. a drying process to reduce the moisture content of the feeds. For example, the moisture content in many feeds can vary from 20% to 60% moisture. In order to achieve optimal gasifier performance, a stable moisture level below 10-20% is most preferred. Further, in order to minimize the risk of steam explosion moisture levels below 10% is generally required.

[0041] For some feed materials one or more of these steps may not be needed and/or will have been previously provided. For example, the feed material (e.g., RDF prepared by a third party) may be received already sized and/or dried. To the extent some or all of this preparation steps are needed, they can be carried using standard waste industry equipment available from multiple vendors (e.g., Alan-Ross Machinery Corporation, Northbrook, N.Y. and others provide suitable sizing equipment).

[0042] The material is fed into a refractory-lined vessel such as an induction furnace, arc furnace or any other type of high temperature molten bath reactor. The reactor design should preferably be selected to assure that (i) it is sufficiently sized for the selected feed volumes and (ii) the amount of molten metal to be contained therein can be controlled at any given time so that the carbon content in the molten bath does not exceed about 4% by weight (based upon the weight of the molten metal). For example, for a 250 tpd MSW processing plant, a 40 ton steel capacity induction furnace preferably should be used, and have additional volume above the molten bath (head space) to accommodate gases rapidly exiting the bath, foaming of the vitreous material and the accumulation thereof during operation.

[0043] The preferred reactor configuration requires the reactor be equipped with the induction channels installed at the bottom of the vessel. Such a configuration is known as a channel furnace (e.g., available from Ajax Tocco Magnetothemic, Inc., Warren, Ohio). Electric power may be supplied in such a manner that electrical current is flowing through the channels. The molten metal may be heated by induction currents induced by alternating current flowing through the coils or loops. This allows unrestricted access to the reactor through the walls for tapping. In addition it allows multiple choices for refractory lining of the top cylinder including carbon graphite brick. As an alternative, a standalone induction furnace may be used to generate a molten bath, which is then charged into the reactor. The channel reactor (as shown in FIG. **4**) is a refractory-lined vessel (**1**) with the molten metal material in it.

[0044] The metal is most typically iron, but other metals such as nickel, chromium, tin, etc. may also be advantageously used (e.g., to effect the conversion of chlorinated material in the feed to desired chlorine-containing form, such as HCl, or if a lower melting metal is necessary or desirable). A preferred variant is to use a separate standard induction furnace to melt steel and then charge it molten into the reactor.

[0045] Steam injection ports, which are located in the reactor above the molten bath layer, are provided. Suitable means to inject a predetermined amount of steam into the reactor include simple steam lances such as stainless steel nozzles manufactured by Spraying Systems Inc. Steam injection is effectively used to control the temperature of the process due to the endothermic reaction of water and carbon. In this process, injected steam reacts with the [C] which is present during operation above the bath, as shown in the following reaction:

$$C+H_2O=H_2+CO \quad dH\sim130 \text{ kJ/mole}$$

This reaction will not only consume excess energy and reduce oxygen consumption but also will yield additional volumes of hydrogen in the exhaust. This is an endothermic reaction, which can rapidly and efficiently reduce the temperature in the reactor without jeopardizing synthesis gas output.

[0046] It is important that the steam be injected above the molten bath or in the vitreous layer, rather that into the metal itself, because most of elemental carbon will float to the top of the melt, and this area above the bath will also be the area which will need to be cooled fastest in case of higher than average heat value product fed into the reactor.

[0047] Oxygen should be injected directly into the metal bath or in the vitreous layer, rather than in the metal itself. Suitable means to inject predetermined amounts of oxygen into the reactor include lances to inject oxygen from the top reactor and tuyere tubes to inject oxygen from the bottom of the reactor. Preferably, oxygen is supplied using one or more supersonic oxygen lances, which generate a gas stream capable of penetrating deep into the metal bath (i.e., the exit of the lances are above the molten metal layer, but sufficiently adjacent thereto so that that the supersonic stream penetrates the molten metal layer). Alternatively, tuyere tubes to inject oxygen into the molten metal from the bottom of the reactor may also be used. Submerged lances and tueyers are possible but they significantly increase the possibility of catastrophic metal spill. Therefore, a preferred method of oxygen supply is by means of supersonic oxygen lances installed above the melt level, which generate a gas stream capable of penetrating deep into the metal bath.

[0048] Oxygen, after being injected into the molten metal, reacts with iron, forming iron oxide. When being fed into the reactor, the material feed submerges into the metal layer of the molten bath, where it is exposed to elevated temperatures in excess of 2900° F. These temperatures immediately initiate thermal decomposition of the material.

[0049] The size of the reactor, the positioning of oxygen and steam injection nozzles, and the form of the exhaust gas passageway, will be selected dependent upon the product throughput and on the type of feed. It is advantageous to have oxygen and steam lances installed in the upper section of the reactor above the molten pool. Supersonic oxygen lances located above the molten pool and pointed downwards deliver oxygen into the bath itself not above it. One of the manufacturers of such lances is Process Technology International Inc, Tucker, Ga.

[0050] During processing, the organic portion of the material is converted into hydrogen and carbon and the inorganic constituents are melted and/or dissolved in the molten bath. The metal oxides are reduced to metals, which accumulate on the bottom of the molten bath, while all other inorganic compounds form the vitreous layer at the top of the molten bath. Carbon formed in this process floats to the surface of the molten bath. While doing so, it reacts with iron oxide reducing it to iron. In addition to this mechanism, direct carbon oxidation by oxygen with the formation of carbon monoxide also takes place. This continuous movement of waste and iron oxide up and iron down in the molten bath provide a necessary stirring action and facilitates the whole process.

[0051] The reactor should preferably be equipped with a tapping mechanism, which may be of the same type which is used to tap blast furnaces and electric arc furnaces. The reactor is equipped with tapping mechanisms for excess metal and for the vitreous layer. The vitreous layer and accumulated metal are periodically tapped to maintain a constant level of the molten bath in the reactor. Suitable tapping mechanisms include: tapping drills, which are supplied by a number of manufacturers (e.g., Woodings Industrial Corporation, Mars, Pa.) and a mud gun to plug the drilled hole. Size and type of the drill and gun will be determined by refractory thickness and its composition.

[0052] Though it is preferable to have a continuous tapping of metal and vitreous material in a full-scale process, similar results can be achieved with periodic tapping of the reactor, which can be easier to implement. While in operation, vitreous material and metal will accumulate in the reactor. The level of the molten bath should be carefully controlled, and if it rises above a pre-set point the tapping mechanism for the metal and/or vitreous material layer will be activated. The simplest and most reliable way to do so is to stop the feed, vent syngas from reactor, then tap sidewall of reactor at the level where the start-up amount of iron would be with standard tapping drill. Vitreous material and metal is then poured out of the reactor until the level of the bath reaches the drilled tapping hole. This hole is then filled with mud through use of a mud gun. This is a short procedure and the reactor is ready for operation again. Metals of suitable composition can be sold (e.g., to foundries) after collection, and the vitreous material may also be beneficially used (e.g., as aggregate).

[0053] Feed material analysis is performed, so as to ascertain the nature of the feed prior to the injection thereof into the reactor, and additional feeds (as discussed below) can be simultaneously injected to address this variability. The process also includes monitoring the composition of the molten metal, the vitreous material, the synthesis gas, and the reactor temperature. The feed can be analyzed either prior to, during, or subsequent to its preparation, with analysis of the feed after its preparation generally being most preferred, because the prior sizing, drying, and air extraction simplifies the analysis.

[0054] Composition, temperature and volume of syngas are continuously analyzed. Concentrations of O_2, CO, CO_2, H_2, H_2S, H_2O and particulate in the syngas are continuously monitored in real time (e.g., using available monitoring equipment such as available from Rosemout Analytical Inc.).

[0055] Further, the compositions of the molten metal and the vitreous material are intermittently analyzed. The metal samples of tapped metal are analyzed for metal composition and melting temperature in any commonly available metallurgical laboratory. If melting temperature of alloy approaches the operating temperature, some pig iron may be added to the feed to lower the temperature. Samples of vitreous material are sent to a laboratory such as Hazen Research Inc., Golden, Co. for oxide composition and carbon content.

[0056] The data from this analysis, together with the analysis of the feed material, are used to control the process as discussed below.

[0057] Steam, oxygen, and/or co-feeds of additional feed materials of higher heat value than the analyzed feed materials are injected into the molten metal bath, with the amounts injected being based upon the analysis and monitoring results as described above. The introduction of steam above the metal bath and oxygen directly into the metal bath are used to maintain the optimal concentration of oxygen in the reactor at all times, and to maintain a reduced oxidation environment. The amount of oxygen and steam injection will be controlled based upon reactor temperature input waste composition data provided by waste analyzer and by exhaust gas composition. Additional feed materials of higher heat value than the analyzed feed materials (e.g., scrap tires or rubber waste, if the principle feed material is MSW) can also be injected to help assure the quality of the syngas (e.g., if a portion of the MSW feed is of lower than desired heat content).

[0058] If the temperature of the bath falls, induction power is increased. In the case of temperature increase, steam may be injected on the top of the bath to cool the process down with endothermic reaction discussed above. Normally water vapor concentration in the exhaust will be low if it increases, carbon concentration of the feed is dropped, and oxygen feed rate will be reduced. Other parameters may also be used to effectively adjust the gas cleanup train's performance.

[0059] The analysis is designed to continuously and accurately estimate the heat value of the feed on a real-time basis prior to injection into the reactor and this can be done by analyzing the compositional makeup of the feed materials. One such analytical approach particularly useful herein is based upon neutron radiation, which is capable of inducing secondary gamma radiation in a wide range of material, and the gamma radiation is specific to elements. Almost all known elements including carbon, silicon, aluminum, calcium, oxygen and hydrogen will emit secondary gamma radiation. For example, when a feed material is irradiated by a neutron beam impulse produced by a neutron beam generator, the material will emit gamma radiation for a short period of time and an associated device measures these gamma ray emissions.

[0060] The spectrum generated thereby is resolved in frequency and time elapsed from the neutron beam pulse and can accurately predict elemental composition (H, C, O, Si, Al, Ca and other element-based concentrations) of the analyzed stream. These measurements are done in a pulse mode, with more than one pulse per second. It typically takes about 15 seconds for software to analyze the signal and generate commands to the control module. Accordingly, the material feed stream analyzer should be installed at a point allowing sufficient time for the system to respond prior waste being fed into reactor. One such suitable neutron beam generator/gamma radiation detector/analyzer system is available from HIEnergy Technologies, Irvine, Calif. or STS-Rateck, St Petersburg, Russia. Through the measurement of the composition of the feed material, a real time estimated heat value of the analyzed stream is established prior the material being fed into reactor. Based upon a predetermined computer algorithm, a controller will then adjust process parameters to better treat the incoming stream. The algorithm generates a theoretical heat value based on the elemental composition of the analyzed feed stream. It also generates required adjustments to the process parameters: feed rate, induction furnace heat, lime or soda ash addition, oxygen and steam flow.

[0061] In addition, the same measurements would preferably be used for estimating inorganic additions to the slag, such as aluminum, calcium, silicon and others. Using this analysis and a computer algorithm, a controlled amount of flux can be added to the feed stream to achieve desired viscosity of the slag layer. Correct viscosity of the slag layer is important because it allows for fast and reliable removal from the reactor. In order to achieve optimal vitreous material removal, its viscosity is preferably about 250 poise at a temperature of 200° F. below the reactor's operation temperature.

[0062] The step of injecting the prepared feed materials into the metal bath is also important. The materials are directly injected into the metal layer. The feed materials can be fed from the top of the reactor into the center of a molten metal bath and are preferably fed directly into the metal layer itself (i.e., the feeding tube is immersed in the molten metal or molten vitreous material). In each instance, it is important that the injection not result in the entrainment or addition of air or inert gases (e.g., use of conventional feeding lances utilizing air or nitrogen for material transport would unacceptably add air into the vessel). The type of feed mechanisms suitable for use in this invention includes auger extruder feeders (e.g., Model No. GPT2-2-400-00, manufactured by Komar Industries, Columbus, Ohio) and ram feeders (e.g., as manufactured by Robson Handling Technology, Recycling Equipment Corporation and others). The feed material (or at least a substantial portion thereof) reaches the bath in a solid form because it is pushed through the feeding tube fast enough not to be gasified in it. It is important that such feed mechanisms assure that waste is delivered underneath and not above the metal or vitreous layers and in a fast enough manner so that the waste does not undergo an unacceptably high rate of decomposition in the feeding tube.

[0063] To achieve these objectives preferably involves one of the following three variants of the feeding step:

[0064] 1. Product from the hopper (**1**) (FIG. **2**) is gravity fed into the charge box (**2**). The gate (**3**) is in a closed position. The ram (**4**) moves forward and compresses the product with high pressure so that essentially all of the air from it escapes through the hopper (**1**). The amount of pressure delivered to the ram, and the sizes of the charge box, are determined by the type of product to be converted and by the required throughput of the overall system.

[0065] 2. Product from the hopper (**1**) (FIG. **3**) is gravity fed into the charge box (**2**). The gate (**3**) is in a closed position. Gate (**3**) opens and the ram (**4**) moves forward, pushing the product into the box (**5**). Gate (**3**) is closed. Gate (**6**) is closed as well. All the air is evacuated by suction (**8**) from box (**5**). Gate (**6**) opens and ram (**7**) moves product into the reactor (**9**).

[0066] 3. Product is forwarded to the hopper. From hopper product is forwarded into extruder feeder, which moves it into the reactor.

[0067] The preferred method of feeding material is into the molten metal itself. When product is fed on the top of the molten bath, special precautions need to be taken to eliminate the possible discharge of the volatile organic compounds, carbon dioxide, and water to the output of the reactor. To avoid this, additional reaction space for the gas phase would preferably be added. This part of the reactor also needs to be furnished with oxygen and steam injection ports to maintain control over the atmosphere in the reactor and allow appropriate corrections if the product stream is changed.

[0068] Product is fed directly into the vitreous layer of the molten bath (see FIG. **4**). In one of the variants, the feeder itself (**1**) is inserted into the metal through the vitreous material. The compressed chunk coming out of the feeder is pushed down through the passageway (**2**) into the reactor underneath the vitreous material (**3**). This feeding arrangement has a significant advantage over top charging, because it eliminates or minimizes the possibility of the presence of volatile organic compounds in the synthesis gas and reduces particulate load on any associated gas treatment system thereby reducing requirements for the reactor size. The end of the feeder can be furnished with grating designed to cut though the compressed log of the material, and by doing so increases product surface area. Though water cooled tubes can be used in this arrangement, it is preferable to use a graphitized alumina unit (such as one manufactured by Vesuvius, Falconer, N.Y.) which is a combination of refractory (graphitized alumina or graphite) bottom submerged section of the tube, and water cooled colorized copper upper section.

[0069] If the product stream includes chlorine- or fluorine-containing compounds, lime can be added into the vitreous material to neutralize them. After being fed into the furnace, the feed product is exposed to the molten bath, whether it sinks into the vitreous material (if fed from the top) or is already submerged into it. The temperature of the molten bath may be as high as approximately 3000° F., or higher. All inorganic compounds are melted. Special fluxes, such as but not limited to, soda ash and borax, may be added to the melt in order to lower melting temperatures for some of the oxides contained in the product. Lime may be added to the feed to correct pH of the vitreous material.

[0070] This process will continuously remove synthesis gas and periodically remove metal and/or vitreous material. These materials are removed through one or more outlets from the refractory-lined vessel and the removal can be accomplished by a conventional means well known in the metal manufacturing and/or waste processing arts. Synthesis gas generated in this process exits the reactor through a top opening. The reactor volume and dimensions above the bath are designed to maximize the synthesis gas production efficiency and to reduce particulate load in the gas stream. Additional boilers, scrubbers and compressors can be installed downstream depending on the specific requirements of the plant.

[0071] During operation, the temperature and level of the molten bath are preferably continuously monitored. When exposed to the extremely high temperatures of the molten bed, organic compounds contained in the feed start to decompose into carbon and hydrogen. Hydrogen will immediately leave the bath. Part of the carbon will dissolve in the molten metal, and the remainder will move toward the top of the bath. Concurrently with the waste, oxygen is feed into the reactor. The oxygen dissolves in iron with the formation of FeO.

[0072] Gas leaving the gas treatment system has heat value ranging from 290 BTU/cft to 450 BTU/cft and will be of suitable quality to be used in combined-cycle (CC) power plant. When such a unit is installed inline with combined-cycle power plant, one would be able to generate 1600 kW of electricity from each ton of material fed into the reactor, which is a significant improvement in comparison with the other waste gasifiers combined with CC power plant.

[0073] The gaseous stream may be further treated as necessary or desirable. A preferred method of treating particulate and impurities in the syngas is to treat it with plasma discharge in a manner which treats these particulate and impurities, but does not significantly oxidize or "burn" the CO portion of the syngas. The types of plasma discharge most suitable include microwave and inductive coupling plasma, which are capable of generating an appropriate type of non-equilibrium plasma electrode-less discharge. In such case, non-equilibrium plasma generators are installed at the inlet of the specially-designed reactor. All, or only the contaminated portion of the syngas, may be fed into the reactor through this inlet. Some oxygen can also be added to the process in order to convert carbon (C) to carbon monoxide (CO). The plasma discharge acts as a catalyst for a number of processes and produces particulate-free syngas at the outlet of reactor. If configured properly, plasma discharge can also convert H_2S contained in the syngas into hydrogen and elemental sulfur, which is separated from the gas stream. Plasma processing does not destroy pollutants in the gas stream by itself, but rather it creates favorable conditions for pollutant removal processes and therefore must be used in conjunction with conventional pollution control technologies.

[0074] Though most of chloride, fluoride and up to 40% of sulfur will be captured in the vitreous material, additional syngas cleaning may be necessary or desirable. In this case, to substantially clean the gas of chlorine, fluoride and sulfur, a dry scrubber, injecting sodium hydroxide or lime, can be installed in the exhaust. After that, ceramic filters or cyclone separators may treat gases, in order to eliminate any residual particulates. Another method is to use a sodium hydroxide solution in the wet scrubber installed before the compressor.

[0075] Though the molten bath and vitreous material layers both act as effective particulate filters, some of the carbon dust, especially when the reactor is fed from the top, can escape the molten bath and become airborne. Special oxygen injection ports may be located above the bath and direct oxygen flow in the upper portion of the reactor in order to supply sufficient amounts of oxidizer to convert carbon dust into carbon monoxide. To prevent particulates from exiting the reactor, the gas-exiting velocity should be lower than the dust-settling velocity. This can be achieved by adding expansion chambers in the exhaust section of the reactor. Another way of minimizing or eliminating particulate material is to install a cyclone on the exit from the reactor.

[0076] The molten bath reactor can be envisioned as separated into zones (FIG. **5**). In the first zone, in the proximity of oxygen lances with excess of oxygen, the following main reactions occur:

$$Fe+\tfrac{1}{2}O_2{=}FeO\ dH{\sim}{-}260\ \text{kJ/mole}(T{=}1600\ \text{K})$$

with FeO being the dominant form of iron oxide in the reactor's preferred operating temperature range. Other reactions include:

$$2Fe+3/2O_2{=}Fe_2O_3\ dH{\sim}{-}800\ \text{kJ/mole}$$

$$[C]+O_2{=}CO_2$$

All products of those reactions travel towards the top of the molten metal bath.

[0077] In the second zone, which has a lack of oxygen, carbon and any non-dissociated material feed are moving towards the top and are dissolved in the melt when they meet iron oxide. Reactions leading to the formation of carbon monoxide occur as follows:

$$FeO+[C]{=}Fe+CO\ dH{\sim}150\ \text{kJ/mole}(T{=}1600\ \text{K})$$

$$Fe_2O_3+[C]{=}2Fe+3CO\ dH{\sim}454\ \text{kJ/mole}$$

$$CO+FeO{=}Fe+CO_2\ dH{\sim}{-}20\ \text{kJ/mole}$$

Carbon participating in this reaction exists in the reactor in three forms: free carbon, carbon dissolved in the melt, and carbon contained in still-not-disintegrated waste. Some of the carbon dioxide formed in zone one is reduced to CO:

$$CO_2+[C]=2CO\ dH{\sim}160\ \text{kJ/mole}$$

This gas continues to react with carbon, forming carbon monoxide. This is an exothermic reaction, which provides a heat source for the process. Special precautions need to be taken not to allow overheating of the system. The temperature of the reactor should be carefully controlled, and if it exceeds 3000° F., steam injection should be activated.

[0078] Heat contained in the gases can be recuperated in a heat exchanger. After the dry scrubber, the synthesis gas will be saturated with water, which may be removed after the gas is compressed (**4**) and cooled below its dew point.

[0079] A concrete example of the process is shown in FIG. **8**. This embodiment is merely representative and not limiting. The system includes a number of components including feed bins **301** and **302**, sensors **303**, a computer control system **304**, feed mixers **305**, feed controllers **306**, composite mixers **307** and **309**, feed controllers **308**, final mixer **310**, syngas production chamber **311** and syngas analyzer **312**. Each feed bin **301** and **302** provides a feedstock material to its associated feed mixer **305**. The feed controller **306** associated with a feed mixer controls the volume of feedstock provide to the composite mixer **307** or **309**. The feed controller **308** associated with each composite mixer **307** or **309** controls the volume of combined feed (created in composite mixer **307** or **309**) supplied to the final mixer **310**. Final mixer **310** provides the combined materials to the syngas production chamber **311**, and the output of the chamber is monitored by the syngas analyzer **312**. The computer system **304** provides the overall system control.

[0080] In particular, to operate this system, sensors **303** and syngas analyzer **312** are used to monitor variation in the feed materials and the syngas production rate. The resultant data are transmitted to a computer program in computer system **304** containing pre-programmed equations that are used to adjust material input rates to achieve the desired syngas production range. In this process, preferably historic data plus real-time test results on the feed material are used to determine the syngas generation potential of each material. Preferably, each feed material is sorted and placed into separate tanks (e.g., feed bins **301**) based on whether it can generate syngas above or below the target syngas production rate. The feed bins **301** hold materials that generate syngas above the target rate, and the feed bins **302** hold materials that generate syngas below the target rate. The number of bins, of course, is merely illustrative. In this embodiment, the resultant two types of feed materials are further mixed, and based on sensor data, fed to the syngas production chamber **311** to produce the target range of syngas production rate.

[0081] Referring to FIG. **8**, in this embodiment, the syngas generation process is optimized by using the computer system **304** to control feed material rates, preferably as determined by real-time syngas composition data and mixing equations. The term "real-time" may also include near or "substantially" real-time data, so there is no explicit requirement that control operations be carried out instantaneously. Additionally, the computer system may also consider historical feed material analysis data, such as elemental content and organic content, with the real-time feed material analysis from the sensors **303** to further optimize the blending of the feed materials and thus the syngas production rate. Further, the analysis on the feed materials by the sensors **303** may also identify potential materials that could upset the syngas generation process, such as materials that contain an excessive level of inorganic compounds. In such case, the particular feed controller **306** might be de-actuated for a given time to ensure that such materials are not provided to the production chamber.

[0082] The process begins after each feed material has been sorted by its syngas generation potential into individual feed bins **301** and **302**. Each feed material is then fed to a feed mixer **305**. The feed mixers **305** could be rotary dryers, traditional mixing tanks, rotating drums or any other device capable of mixing each feed material to produce a consistent composition. Materials in feed bin **301**, which have a syngas generation potential above the target syngas production rate, preferably are fed by computer system **304** to an "above" composite mixer **307**, while materials in feed bin **302**, which have a syngas generation potential below the target syngas production rate, preferably are fed by the computer system **304** to a "below" composite mixer **309**. Preferably, materials from the composite mixer **307** and composite mixer **309** are then fed at specific rates as determined by the computer system **304** into a final mixer **310** prior to being fed to the syngas production chamber **311**. A representative production chamber **311** is of the type described in U.S. Patent Application Publication No. 2006/0228294, or as described in U.S. Pat. No. 5,571,486. The particular production chamber **311** is not a limitation of the present invention.

[0083] The size of the mixing tanks, the material feed rates, and the residence/mixing time of each material are ultimately determined by the target range of syngas production rate. For example, a narrow target range will require larger tanks and longer mixing times.

[0084] A feed controller **306**, controlled by the computer system **304**, sets the feed rate of each feed mixer **305** by adjusting the operating parameters of the physical dispensing device. A dispensing device could be a screw drive, a conveyor system, or any other mechanical means of moving feed material from the feed mixers **305** to the composite mixers **307** and **309**. Also, it is assumed that simple level sensors are used to ensure that the dispensing devices that move materials from the feed bins **301** and **302** to the feed mixers **305** operate in a manner that, in a preferred embodiment, ensure each feed mixer **305** remains full at all (or substantially all) times.

[0085] A sensor **303** monitors each feed stream. These sensors may include, but are not limited to, devices that measure secondary radiation such as a CMOS or CCD image sensors plus a source of primary radiation including white or infrared light. Feed material sensor data is then sent to the computer system **304**. This data may be used to detect variation in the composition of the feed stream. Preferably, this information is used by the computer system **4** as an adjustment factor in determining the feed rates to the composite mixers **307** and **309**, and final mixer **310**.

[0086] Immediately after exiting the syngas production chamber **311**, and after any required cooling, a syngas analyzer **312** determines the syngas production rate. Production data include, but is not limited to, the determination of volumetric flow rate, hydrogen gas concentration, and carbon monoxide concentration. Potential methods for rapid syngas analysis include, but are not limited to, Raman Spectroscopy and GC Mass Spectroscopy (GCMS). Data from the syngas analyzer **312** is sent to the computer system **304**.

[0087] After receiving continuous real-time data from the feed controllers **306** and **308**, the material sensors **303**, and the syngas analyzer **312**, the computer system **304** then relates the target production rate and target energy content data with the real-time feed rate and composition data. The computer system **304** then executes a computer program based, for example, on the equations presented below, to maintain the syngas at the target production rate and target energy content. As noted above, typically the target production rate is controlled by adjusting the feed rate of the material into the gasifier, whereas the target energy content typically is controlled by having the computer system **304** inform each feed controller **306** and **308** to dispense the appropriate amount of the feed materials into the composite mixers **307**, **309**, and **310**.

[0088] The number and organization of the feed bins and feed mixers shown in FIG. **8** is also merely representative of the general concept shown in FIG. **6**, and the present invention should be deemed to cover all such embodiments, however configured.

[0089] FIG. **9** illustrates a more simplified embodiment where only a single feedstock Product **2** is added (blended or mixed) to a primary feedstock, Product **1**, in this case construction and demolition waste (C&D). In the drawing the Product **1** feeder is illustrated by reference number **400** and the Product **2** feeder is illustrated as reference number **402**. The materials are combined in blender/mixer **404** and provided to gasifier **406**. The output syngas **410** is analyzed to provide a gas analysis **412**, which is then provided to the computer system **414** to provide the one or more feedback control signals **416** and/or **418** to the respective feeders.

[0090] In this example, the C&D waste is being processed in a facility that may include several stages (not shown): C&D handling and sorting, C&D pre-processing, C&D debris post-processing, gasification, and, optionally, post-gasification/energy generation. These stages may be carried out in a single building, facility or enclosure, or in co-located processing facilities. Thus, for example, the handling and sorting, and pre-processing stages are performed in a first enclosure, while the post-processing and gasification stages are carried out in a second, nearby building, facility or enclosure. Preferably, the C&D processing takes place in a continuous or partially-continuous manner as bulk debris is received at the processing facility. A representative end-to-end system of this type is described in U.S. patent application Ser. No. 12/021,987, filed Jan. 29, 2008, the disclosure of which is incorporated herein by reference.

[0091] As noted above, an object of having multiple feeds is to equalize the BTU content of the feed materials to the gasifier to produce a constant or substantially constant BTU gas output. In this example, construction and demolition wastes (C&D), which have been appropriately sorted and dried, are provided as the main feed component to the gasifier. Because it is a waste material, the incoming BTU content ranges from approximately 5,000-7,000 BTU/lb; thus, for a constant system feed rate, the energy content of the output gas would vary percentage-wise equally. Preferably, the product syngas has a content of approximately 325 BTU/lb. To produce a constant BTU output, it is thus necessary to add a higher BTU content material. In this example, this higher BTU content material (Product **2**) is waste rubber (e.g., chrome rubber), which has a consistent content of more than 10,000 BTU/lb. The rubber is blended or mixed with the C&D waste in blender/mixer **404**. The blend ratio may be set volumetrically, although this may not be an optimal approach. Thus, preferably, the system uses one or more of GCMS, infrared and other analytical equipment to measure for hydrogen, carbon monoxide, methane and other hydrocarbons, as well as for mass flow.

[0092] The results of the analysis **412** are fed to a combination computer/PLC system **414**, which utilizes the analytical data in conjunction with mass flow and energy content of the various species to determine a real-time (or near real-time) syngas energy value. This energy value when compared to the desired value enables the computer system **414** to produce a signal **418** to speed up or slow down the high BTU feed stock or, in the case of a higher desired mass flow, to enable the computer system **414** to produce a signal **416** to slow down the primary feed stock (and perhaps the rubber feeder as well) while maintaining BTU content. These output signals are produced in real-time (or substantially near real-time) to minimize energy fluctuations in the syngas. Preferably, materials are fed to the system with gravimetric feeders **400** and **402**.

[0093] Of course, the particular type of waste material that is added to the primary feed will vary depending on the primary feed characteristics and BTU content, the availability of other feed stocks, as well as the energy content of those additional materials. Thus, for example, in appropriate circumstances municipal solid waste (MSW) may be used as an additive, as its energy content (approximately 4,000-5,000 BTU/lb) varies more than most other waste streams. Most areas of the world produce MSW, so it may be a convenient additive. Of course, higher BTU content material availability will vary considerably depending on location.

[0094] FIG. **10** shows another embodiment. The system utilized here is an expansion of that shown in FIG. **9**. Here, one or materials of lower BTU content are fed with one or more high energy content materials, such as waste plastics, paper, rubber, or sludge to produce a constant output gas. In this example there are four materials (**500**, **502**, **504** and **506**) although this is not a limitation. The mentioning of specific high energy wastes is not to be inclusive, but only an example of such feed stocks. Preferably, the system described here also incorporates component availability and switches automatically from one high energy product to another as needed.

[0095] Representative mixing calculations are now described. In particular, it can be shown via an energy balance on the syngas production chamber **311** that the energy potential (E) of the feed material entering the production chamber **311** must be equal to the energy generated (R) by the combustion reaction within the chamber. If X is the mass feed rate to the chamber **311** and H is the energy potential per mass unit of the feed material, it can be shown the incoming potential energy rate (E) is equal to the product of X and H, which is equal to the energy R generated by the production chamber:

$$E(\text{energy/time})=X(\text{mass/time})\times H(\text{energy/mass})=R(\text{energy/time}) \quad (1)$$

Because a constant mass feed rate to the chamber **311** and a steady state process is assumed, and because it is also assumed the energy potential of the feed materials to the composite mixers (**307**, **309**) is constant, the cumulative mass feed rate of the mass streams exiting the composite mixing tanks (**307**, **309**) must be equal to mass feed rate entering the chamber. Thus, if HL is the "below-target" energy potential of the feed stream from the composite mixer **307** and HH is the "above-target" energy potential of the composite mixer **309** and X_b and X_a are the respective mass rates exiting the composite mixers **307** and **309**, it can be shown that:

$$(HL(\text{energy/mass})\times X_a(\text{mass/time}))+(HH(\text{energy/mass})\times X_b(\text{mass/time}))=R(\text{energy/time}) \quad (2)$$

[0096] A target energy generation level can be represented via the following variables:

[0097] R_t=target energy generation rate,

[0098] R_1=lower limit energy generation rate, and

[0099] R_u=upper limit energy generation rate.

[0100] Now, because the actual energy (R_a) generated by the production chamber **311** can be accurately deduced from composition measurements made by the syngas analyzer **312**, the variation in the energy generation rate (R_v) from the target level can be established:

$$R_v=R_a-R_t \quad (3)$$

[0101] Consider if R_v is positive. This indicates the feed rate X_a to composite mixer A (which has the lower energy potential HL) must be increased and the feed rate X_b to composite mixer B (which has the higher energy potential HH) must be decreased by an equivalent mass rate to decrease the overall variation R_v.

[0102] Ultimately, to produce an energy generation rate within a target range, preferably calculations that employ differential equations are iterated by the computer system. **304**. Also, prior to executing these calculations an initial design should be established, based upon a target energy production range for specific mass feed rate that specifies the volume of each mixing tank. For example, for a given mass feed rate, larger mixing tanks produce longer residence times for a given feed material, which decreases variations in material concentration over time (which subsequently decreases the rate of variation of energy generation by the production chamber **311**).

[0103] The following is a sample calculation. Using applied differential equations and assuming perfect mixing due to the relatively minute change in the overall composition within each mixer caused by the addition of new feed material, it can be shown that the time rate of change for a given feed material, A is given by the following equation:

$$dA/dt=\text{rate of amount gained}-\text{rate of amount lost} \quad (4)$$

[0104] Because the volume of any mixing container is known, i.e., constant, a differential equation can be created for each mixing vessel that can render a solution for the mass of A present in a mixing vessel at any given time. For example, if A is entering a mixing vessel at 10 pounds per minute and there is 5 pounds of A in the tank initially:

$$dA/dt=10-A/5 \quad (5)$$

Solving this equation, it can be shown that:

$$A=50-25(e-t/5) \quad (6)$$

Thus for the given feed rate, a set time can be entered to determine the mass of A present in the system. This mass value can then be multiplied by the syngas generation density, i.e., the amount of syngas generated by unit of mass of A, to calculate the syngas production rate for A.

[0105] The computer system **304** can execute similar calculations for each feed material to determine its contribution to the overall syngas production rate and then adjust each feed rate via the controller modules **306** to optimize the target syngas production rate based upon the sensor data. For example, if the syngas analyzer **312** reports a syngas production rate that is below the target range, the feed rate of the "above-target" materials can be increased and the feed rate of the "below-target" materials can be decreased to keep the syngas production rate within the target range.

[0106] Further, although an embodiment of the invention has been described in the context of an "above-target" and "below-target" materials, there may be multiple such levels (such as below, intermediate, above, or the like) or even just one level.

[0107] FIG. **7** illustrates a representative computer system **304**. A data processing system **200** suitable for storing and/or executing program code will include at least one processor **202** coupled directly or indirectly to memory elements through a system bus **205**. The memory elements can include local memory **204** employed during actual execution of the program code, bulk storage **206**, and cache memories **208** that provide temporary storage of at least some program code to reduce the number of times code must be retrieved from bulk storage during execution. Input/output or I/O devices (including but not limited to keyboards **210**, displays **212**, pointing devices **214**, etc.) can be coupled to the system either directly or through intervening I/O controllers **216**. Network adapters **218** may also be coupled to the system to enable the data processing system to become coupled to other data processing systems or devices through intervening private or public networks **220**.

[0108] The computer may be connected to another computer or system over a network, such as wide area network (WAN), local area network (LAN), protected network (e.g., VPN), a dedicated network, or some combination thereof. More generally, the various system components illustrated in FIG. **8** may be controlled with any collection of one or more autonomous computers (together with their associated software, systems, protocols and techniques) linked by a network or networks. The control system calculations comprise a set of preferably software-based functions (e.g., applications, processes, execution threads, or the like) or firmware-based functions that provide the described mixing method.

Example

[0109] Dried pelletized refuse derived fuel (RDF) with a capacity of 250 tons per day (TPD) is processed in a 40-ton channel induction reactor (Ajax Model VS-40), modified to have a sealed lid and increased dimensions to provide additional head space. RDF at a rate of 10.4 tons an hour (TPH) is fed into the reactor through a feeding mechanism, consisting of a screw type educator feeder. This feeder accomplishes two tasks: air extraction from the RDF, and product movement with the required speed to the feeding tube. The feeding tube is a graphitized alumina pipe with internal diameter (ID) of 4". It is installed in the center of the reactor lid.

[0110] The RDF feed material as received has moisture content of about 35% and contains material of varying size. The feed material is prepared as follows: it is dried using a Eagle II (available from Sweet Manufacturing Company, Springfield, Ohio) to a moisture level of 7%, sized using a shredder (Model # VVZ-310 available from Vecoplan, LLC, High Point, N.C.) to an average size of about 1 inch, and air is extracted from the dried and sized feed material using an extruder/feeder (Model # GPT2-400-0, manufactured by Komar Industries, Columbus, Ohio), resulting in the feed material having less than about 1% air by weight.

[0111] The composition of the prepared material is then analyzed for C, H, O, Al, Si, Ca, Fe, Ni and other components and the heat content thereof is predicted using a neutron beam analyzer (Model # NBW-1 available from STS-Ratek, St. Petersburg, Russia).

[0112] The reactor lid is also equipped with oxygen and steam lances and a gas outlet. The reactor is sealed from the atmosphere and is initially charged with 40 tons of molten iron. Oxygen is continuously fed into the reactor at a rate of 66,000 cubic feet an hour (cft/hr). Organic materials are decomposed in the reactor with formation of 325,000 cft/hr of H, 256,160 cft/hr of carbon monoxide and 1700 lb/hr of vitreous organic material. Gaseous products exit the reactor through the exhaust passage. The vitreous organic material is accumulated in the form of slag layer on top of the bath.

[0113] The temperature and level of the bath, the gas composition, and the temperature and volume of the syngas leaving the reactor are each measured. The composition of the syngas is continuously analyzed for CO, H_2, H_2O, O_2, H_{25} using a gas analyzer (Model # MLT 4 available from Emerson, St Louis, Mo.). The composition of the metal and the vitreous layers are intermittently analyzed in a commercial metallurgical laboratory.

[0114] The results of these measurements are used to control amounts of oxygen, steam, and/or co-feeds into the reactor. When the temperature of the molten bath rises above desired level, steam injection into reactor is activated and the endothermic steam shift reaction results in temperature reduction of the process and additional hydrogen production. When the compositional analysis of the feed material indicates that it is below a predetermined heat value, additional oxygen and/or scrap tires (which is a higher BTU value co-feed than RDF) are injected into the reactor to maintain the BTU value of the syngas in a range between 350 and 450 BTU/cu ft.

[0115] After a predetermined amount of vitreous organic material accumulates in the reactor, the level of the molten bath rises to the desired level. Feed to the system is interrupted and oxygen feed is gradually phased out. The reactor is purged of combustible gases and a tap hole is drilled in the sidewall of the reactor at the level of the original metal bath. All products accumulated in the reactor above this hole are poured out into a specially designed cart. The vitreous organic material and metal are later separated with metal being available for sale to (e.g., steel mills) and the vitreous organic material being available for use as construction aggregate. After the tapping operation is completed (which typically takes about 40-60 minutes), the tap hole is sealed with a mud gun and processing of the waste into combustible gas resumes.

[0116] While the above describes a particular order of operations performed by certain embodiments of the invention, it should be understood that such order is exemplary, as alternative embodiments may perform the operations in a different order, combine certain operations, overlap certain operations, or the like. References in the specification to a given embodiment indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Further, while given components of the system have been described separately, one of ordinary skill will appreciate that some of the functions may be combined or shared in given systems, machines, devices, processes, instructions, program sequences, code portions, and the like.

[0117] Having described our invention, what we now claim is set forth below.

1-16. (canceled)

17. A method of producing syngas using a gasifier, comprising:

establishing a target production rate and a target energy content for syngas output from the gasifier;

providing at least first and second feed materials as a mixture to the gasifier;

monitoring syngas being produced by the gasifier; and

based on data obtained by the monitoring step, adjusting a feed rate of the mixture to attempt to maintain the target production rate, and adjusting a feed rate of at least one of the first and second feed materials to attempt to maintain the target energy content.

18. The method as described in claim **17** where the first and second materials each have different energy content.

19. The method as described in claim **17** further including: analyzing data generated by the monitoring step to identify levels of carbon monoxide, hydrogen and total hydrocarbons in the syngas; and determining BTU content of the syngas.

20. The method as described in claim **17** where the first feed material is construction & demolition (C&D) waste.

21. The method as described in claim **20** wherein the second feed material is one of: municipal solid waste (MSW), rubber, refuse derived fuels, wastewater sludge, scrap tires, and combinations thereof.

22. The method as described in claim **17** wherein the monitoring is initiated after the gasifier is at a steady state.

23. A method of syngas production using a syngas production chamber, comprising:

establishing a target production rate at a target energy content;

providing a set of one or more first feed materials, where each of the set of one or more first feed materials has a BTU content value above the target energy content;

providing a set of one of more second feed materials, where each of the set of one or more second feed materials has a BTU content value below the target energy content; and

prior to gasification in the syngas production chamber, mixing first feed material and second feed material to create a mixture;

controlling a feed rate of the mixture into the syngas production chamber such that an output mass flow rate of the syngas from the syngas production chamber is maintained at or near the target production rate;

controlling a feed rate of at least one of the first feed or second materials such that the syngas output from the syngas production chamber is maintained at or near the target energy content.

24. The method as described in claim **23** wherein at least two of the first feed materials are mixed prior to mixing the first feed material and second feed material.

25. The method as described in claim **23** wherein at least two of the second feed materials are mixed prior to mixing the first feed material and second feed material.

26. The method as described in claim **23** wherein at least two of the first feed materials are mixed and two of the second feed materials are mixed prior to mixing the first feed material and second feed material.

27. A computer-implemented method of controlling syngas production where first and second feed materials are mixed and supplied to a gasifier, comprising:

establishing a target production rate and a target energy content for syngas output from a gasifier;

controlling a feed rate of a mixture of the first and second feed materials into the gasifier such that an output mass flow rate of the syngas from the gasifier is maintained at or near the target production rate; and

controlling a feed rate of at least one of the first feed or second materials such that the syngas output from the gasifier is maintained at or near the target energy content.

* * * * *