Barrington Place, Rockwood, TN 37854 (US). THOMPSON, David, C; 112 Chatham Circle, Madison, AL 35758 (US).


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(54) Title: METHOD OF USING INJECTOR SYSTEM FOR MAKING FUEL GAS

(57) Abstract: A gasifier for producing synthesis gas from a widely varying feedstock of waste and natural fuels, the gasifier including an injector system having several integrated lances mounted to a molten metal bed reactor or other gasification reactor chamber. The gasification reactor chamber is required to contain the reaction for the production and collection of a fuel gas. The lances are mounted through the top, side and bottom of the reactor in order to selectively direct materials into the molten metal, slag and freeboard gaseous area above the molten metal and slag.

FIG. 1
NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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Description

METHOD OF USING INJECTOR SYSTEM FOR MAKING FUEL GAS

Technical Field

The present invention relates to an injector system for producing synthesis gas. More particularly, the present invention relates to an integrated set of injection lances for producing a high quality synthesis gas from a widely varying feedstock of waste and natural fuels, the lances being used in combination with various types of molten metal furnaces.

Background Art

Conventional gasification is a process that converts carbonaceous materials, such as coal, petroleum, petroleum coke or biomass, into carbon monoxide, hydrogen and carbon dioxide. In a conventional gasifier, the carbonaceous material undergoes three processes including pyrolysis, combustion and gasification. During the pyrolysis process, the carbonaceous material heats up, volatiles are released and char is produced. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions. The combustion process occurs as the volatile products and some of the char reacts with oxygen to form carbon dioxide and carbon monoxide, which provides heat for the subsequent gasification reactions. The gasification process occurs as the char reacts with carbon dioxide and steam to produce carbon monoxide and hydrogen. The resulting gas is called synthesis gas or syngas. Synthesis gas is typically combusted in a gas turbine, and the heat is used to produce steam to drive a steam turbine.

There are four basic types of gasifiers operating today including fixed bed systems, fluidized bed systems, entrained flow systems and molten bed systems. In a fixed bed reactor, a reactive gas or gases are passed through a fixed bed of feedstock in a co-current or counter current flow. The fixed bed consists of carbonaceous fuel (e.g. coal or biomass) through which a "gasification agent" (steam, oxygen and/or air) flows in a co-current or counter-current configuration. The ash is either removed dry or as a slag. The nature of a fixed bed gasifier means that the fuel must have high mechanical strength and must be non-caking so that it
will form a permeable bed. Thus, certain feedstocks such as processed municipal solid waste, biosolids, ground coal and certain types of biomass are not suited for use in fixed bed reactors. This is particularly true when moisture is present.

In a fluidized bed reactor, the pressure drop of the gasifying reactants is adjusted so that the feedstock is lifted or suspended by the gaseous phase. In particular, the carbonaceous fuel is fluidized in oxygen (or air) and steam. The ash is removed dry or as heavy agglomerates that defluidize. The temperatures are relatively low in dry ash gasifiers, so the fuel must be highly reactive; low-grade coals are particularly suitable. Fluidized bed gasifiers are most useful for fuels that form highly corrosive ash that would damage the walls of slagging gasifiers. Biomass fuels generally contain high levels of corrosive ash.

In an entrained bed reactor the solid particulate feedstock are carried or "entrained" through the reactor by the reacting gases. In particular, a dry pulverized solid, an atomized liquid carbonaceous fuel or a fuel slurry is gasified with oxygen in co-current flow. The gasification reactions take place in a dense cloud of very fine particles. Most coals are suitable for this type of gasifier because of the high operating temperatures and because the coal particles are well separated from one another. The fuel particles must be much smaller than for other types of gasifiers. This means the fuel must be pulverized, which requires somewhat more energy than for the other types of gasifiers. It also means that feedstocks such as processed municipal solid waste, certain biomass, spent tires and several types of industrial wastes are not well suited for this type of gasifier.

In a molten bed reactor higher heat value feedstock (primarily coal) is injected into a molten bath of iron, salt or coal ash contained within a reactor. A reactive gas such as oxygen, steam and/or carbon dioxide is injected into the vessel to control the rate of reaction within the reactor. A shortcoming of current molten bed gasifiers is the inability to process low heat value feedstocks and thus widely varying feedstocks. Often this is because low heat value feedstocks such as municipal solid waste, certain biomass wastes and some household and industrial wastes, when introduced into a molten bath by conventional injection systems, can consume rather than produce heat thus limiting the efficiency of the reactor and
possibly endangering the continuity of the process itself. Further, existing injector systems are not configured to handle a widely varying feedstock in terms of variations in particle size, particle density, material heat value and multiple states of matter (i.e. simultaneous injection of solids, liquids and gases). In addition, existing injection systems are not configured to meter the precise amounts of reaction gases necessary to maintain an exothermic reaction for the widely varying feed stream with real time feedback on exothermic state and synthesis gas quality to maintain increased production rates.

An exemplary molten bed reactor is described in U.S. Patent No. 4,738,688 for gasifying carbonaceous material including a multi-nozzle, top-blowing lance of the non-immersion type. The lance includes a central nozzle for blowing the carbonaceous material in a powdery form into a furnace body containing a high temperature molten iron bath. A carrier gas selected from air and \( \text{N}_2 \) is used to blow the carbonaceous material through the lance. A plurality of inner nozzles for blowing a gasifying agent surround the central nozzle are also provided.

Another exemplary molten bed reactor is described in U.S. Patent No. 4,043,766. This patent discloses a slag bath generator including reactor vessel having a sidewall through which a number of nozzles extend. A fine-grain fuel, e.g., coal, and gasification medium, e.g., steam and/or oxygen, are fed through the nozzles to provide jet streams. This nozzles are arranged such that an angle of \( 10^\circ \) is formed between the vertical plane containing the jet streams and a tangential vertical plane at the point of impingement of the jet streams upon the surface of the liquid slag at the relevant cycle.

U.S. Patent No. 4,565,551 discloses a coal gasification apparatus including a lance which has a main nozzle for injecting powdery coal and a plurality of subsidiary nozzles, usually three in number, for injecting a jet of stream of oxygen carrying a supplementary agent, i.e. steam, carbon dioxide, hydrocarbon gases, or a mixture thereof. The subsidiary nozzles are symmetrically provided surrounding the main nozzle. The junction point is located far enough from the injecting end of the nozzles to thoroughly commingle the agent with the oxygen gas before the two are injected from the lance.
U.S. Patent No. 4,738,688 discloses a process for gasifying carbonaceous material including a lance body including a powder blowing nozzle in the center thereof. Through this center blowing nozzle, the carbonaceous material in the form of powder in a carrier gas therefore is injected into molten iron. A first plurality of nozzles for blowing a gasifying agent are provided surrounding the powder blowing nozzle. Preferably, they are on a circle concentric with the central nozzle. Another plurality of nozzles are provided along an outer periphery, surrounding the first plurality of nozzles.

U.S. Patent No. 4,545,786 discloses an apparatus for gasifying a solid carbonaceous materials including blowing lances which can feed raw material coal, oxygen and carrier gas into molten iron. The blowing lances have single nozzles that include a central nozzle and peripheral nozzle arranged around the central nozzle. A mixed fluid of steam and coal is blown out through the central nozzle and oxygen is blown through the periphery nozzles.

U.S. Patent No. 4,389,246 discloses a gasification process of solid carbonaceous material including a non-submerged lance with multiple nozzles which enables coal and carrier gas, oxygen and steam to be blown through one lance via three types of nozzles. In particular, the lance includes a center nozzle, an annular slit nozzle encircling the center nozzle and three triangularly located nozzles at the peripheral portion of the annular slit nozzle. Through the center nozzle is blown a mixture fluid of coal and the carrier gas, through the slit nozzle is blown steam, and through the peripheral nozzles is blown oxygen, respectively.

**Disclosure of the Invention**

The motivating object of the present invention was the need for a superior waste to energy conversion process allowing for increased fuel flexibility. Specifically, for this invention, the goal is to efficiently and economically produce a high quality synthesis gas from low heat value, widely varying feedstock. Widely varying feedstock can include waste materials contaminated with inorganics as well as low grade natural fuels and industrial by-products as described in Table 1.
The resulting synthesis gas is of sufficient quality to allow production of electrical power, refining of Fischer-Tropsch liquids, production of methanol or the
separation of industrial grade hydrogen. In addition, the present invention provides for improved environmental impact and clean and more environmentally friendly energy production while improving upon current industrial conversion efficiencies. Further, the present invention provides a major new source of energy from material that is currently considered useless, hazardous or not worth harvesting.

By fuel flexibility it is meant that the injector of the present invention is capable of handling a broad range of wastes from municipal waste, medical waste, biomass to bio-solids, spent tires, and industrial/agriculture waste. This includes a wide range of natural fuels and waste fuels. Further, the injector of the present invention can process solids, liquids and gaseous feed streams simultaneously in a single reactor, as well as low heat value feed (3,800 BTU/lb) as raw material. Additionally, the injector can tolerate a large content of in-organics and contaminants in the carbonaceous feedstock.

By efficiency and economics it is meant that the injector, in combination with certain types of molten metal furnaces, exhibits an end to end plant conversion efficiency of at least 58% to about 65% while operating at ambient pressure, using no air and efficiently using oxygen. It also means that the injector can process large quantities (as high or higher than 700 tons per day) of varying feedstock in a single reactor vessel. Further, the injector can maintain an exothermic reaction state, thus requiring minimal external heat assist, and generate high quality synthesis gas (typically 250 - 350 BTU/scf) with a low particulate level.

By environmental impact it is meant that the injector, in combination with certain types of molten metal furnaces or other gasifier reaction chambers, produces no char, minimal ash, no tar, no oils, no phenols and no ammonia while producing useable by-products such as siliceous slag and pig iron. The injector can also efficiently and safely processes high sulfur and contaminated coal and several types of industrial and household hazardous waste. Further, the injector can recycle and dissociate polluting exhaust gases and green house gases such as carbon dioxide, dioxins, furans, volatiles organic gaseous compounds, nitrous oxides and the like.

In order to meet the objectives of the invention there is provided an injector system including- several integrated lances mounted to a molten metal bed reactor
or other gasification reactor chamber. The gasification reactor chamber is required
to contain the reaction for the production and collection of a fuel gas. The lances
are mounted through the top, side and bottom of the reactor in order to selectively
direct materials into the molten metal, slag and freeboard gaseous area above the
molten metal and slag. The purpose of the injector system is to inject the widely
varying feed stock with the precise type and amount of reaction gases to the proper
region of the reaction chamber in order to produce and sustain an increased
exothermic reaction and thus increase the gasification efficiency.

**Brief Description of Drawings**

FIG. 1 is a partial sectional view of a gasifier that includes an injector
system in accordance with a preferred embodiment of the present invention.

FIG. 2 is a sectional view of the gasifier showing the chemical reactions
that take place at specific locations within the gasifier during a gasification reaction.

FIG. 3 is a partial sectional view of a multi-port center main injection lance
in accordance with a preferred embodiment of the present invention.

FIG. 4 is a partial sectional view of a gasifier including the multi-port
center main injection lance of FIG. 3 and showing the injection regions and
injection port directions of the lance.

FIG. 5 is a partial sectional view of a gasifier including an integrated set of
lances in accordance with a preferred embodiment of the present invention
consisting of a multi-port center main lance and four top perimeter lances and
showing the associated reaction volume of each lance and their interaction with a
molten bed.

FIG. 6 is a partial sectional view of a top perimeter lance in accordance
with a preferred embodiment of the present invention.

FIG. 6a is a partial section view of a second embodiment of a top perimeter
lance in accordance with a preferred embodiment of the present invention.

FIG. 7 is a partial sectional view of a gasifier including an integrated set of
lances in accordance with a preferred embodiment of the present invention
consisting of a multi-port center main lance and four top perimeter lances and
showing variations in lance stand-off positioning above a molten bed.
FIG. 8 is a partial sectional view of a gasifier including an integrated set of lances in accordance with a preferred embodiment of the present invention consisting of a multi-port center main lance and four top perimeter lances and showing two levels of counter-rotating cyclonic flow above a molten bed.

FIG. 9 is a partial sectional view of a gasifier including an integrated set of lances in accordance with a preferred embodiment of the present invention consisting of a multi-port center main lance and four top perimeter lances and showing counter-rotational turbulent flow injection above a molten bed.

FIG. 10 is a top plan view of a side lance injector set showing the injection regions and injection port directions of the lances onto a molten bed of a gasifier.

FIG. 11 is a partial sectional view of a gasifier including an integrated set of lances in accordance with a preferred embodiment of the present invention consisting of a multi-port center main lance, four top perimeter lances, two side lances and two bottom injection lances showing the injection regions and injection port directions of the side and bottom lances.

FIGURE 12 is a partial sectional view of a free board injection lance in accordance with a preferred embodiment of the present invention.

FIGURE 13 is a partial sectional view of a gasifier including three free board lances in accordance with a preferred embodiment of the present invention showing a multi-level opposing cyclonic flow created by the lances.

FIGURE 14 is a partial sectional view of a gasifier including three free board lances in accordance with a preferred embodiment of the present invention showing a center focused and an outward focused opposing turbulent flow created by the lances.

FIG. 15 is a sectional view of a means for sealing and positioning the various injection lances of the invention.

FIG. 16a is an elevation view of a fixed section of lance positioning mechanism according to a preferred embodiment of the present invention.

FIG. 16b is an elevation view of a floating section of the lance positioning mechanism of FIG. 16a.
**Best Mode for Carrying Out Invention**

This is an integrated, multiple lance injection system capable of processing a widely varying feed stream of both organic and inorganic material. Five distinct injector hardware systems are integrated into a continuous, interactive process designed to inject carbon and hydrocarbon containing material in solid, liquid and gaseous form. A significant range of contaminant materials can be tolerated and effectively rendered safe by the process. The primary feed stream materials include, but are not limited to, the materials listed in Table 1. By "feed stream" it is meant a continuous or intermittent flow of materials. This injection system can be utilized on a wide variety of gasification reactors to improve the production of synthesis gas. This injection system can also be fitted on existing molten bed reactors to facilitate their conversion to a gasification system. Three distinct gasification zones are created by the injector within a single gasification reactor. These gasification zones are separately controlled but interactive in that the measured reaction intensity and characteristics of one zone influence the injector inputs to the other zones through a real time feedback and control loop. The integrated multiple lance system allows the following enhanced features for improvement of synthesis gas production:

a) Integrated and simultaneous top, side and bottom material injection;

b) Variable injection speeds from subsonic to sonic and to supersonic tip velocities;

c) Real-time variable stand-off distance from injector tip to gasification material or reaction bed;

d) Generation and control of several distinct molten metal gasification reaction volumes within the gasification vessel;

e) Generation and control of a secondary or froth reaction zone thus increasing synthesis gas production capability from a single reactor;

f) Generation and control of horizontal stirring and mixing of molten metal and slag controlled by multiple side lance injection integrated with top lance injection;

g) Generation and control of off-take region to limit froth zone vertical growth;
h) Control of the off-take zone thermodynamic characteristics to provide additional synthesis gas production zone;

i) Generation and control of vertical stirring and mixing of molten metal from controlled top lance injection speed, injection angle, material content and stand-off distance; and

j) Highly instrumented lances with temperature and flow characteristics data for system level optimal feedback and control.

The arrangement and controlled, real-time adaptability of these distinct injection systems facilitates the operation of multiple gasification regions, each with its own characteristics within a single gasification reactor. This unique arrangement of hardware with constant monitoring and control of gasification reaction conditions provides the flexibility to exercise real-time optimal control upon the process. This results in maximum generation of quality synthesis gas with minimum expenditure of energy.

Each set of lances is configured to accommodate a specific group of feed stream constituents. The arrangement and design of these lance sets is based upon generating maximum quantities of quality synthesis gas at minimum operational cost. Solids, liquids and gaseous feed materials are injected in the specific section of the reaction chamber or gasifier that insures optimum penetration or reaction for the material's density and heat value.

The combination of material to be gasified determines the proper amount of oxygen, carbon dioxide and/or steam that must be formed to insure that the overall process is an exothermic reaction. This results in the maximum generation of synthesis gas for the minimum expenditure of energy.

For the molten metal gasifier, a molten iron bath, saturated with carbon (typically 3% to 4% by weight) is used as a catalyst for carbon and hydrocarbon exchange in the presence of controlled amounts of oxygen, carbon dioxide and/or steam. This reaction can be carried out in a variety of molten metal furnaces. The reaction vessel within the furnace is equipped with top, side and bottom mounted high speed injectors to place carefully measured amounts of carbon or hydrocarbon material in the proper region of the molten metal or freeboard reaction zones with
the correct amount of oxygen, carbon dioxide and/or water vapor to sustain the maximum exothermic reaction. Reaction volumes within the molten metal are created by each injection lance. Instrumentation utilizing one or more two color optical cameras, one or more infrared cameras and multiple thermal and acoustic sensors provide data on the intensity and size of each reaction volume. This data is digitized and sent to an advanced control system which monitors and adjusts the injection inputs to each reaction volume in the furnace to maintain maximum intensity. In this way, the carbon content of the iron remains at or near its saturated value while the injected carbon/hydrocarbon material and oxygen are combined to form hydrogen (H₂) and carbon monoxide (CO), the primary constituents of the fuel gas. Depending upon the nature of the carbon or hydrocarbon feed stream, the reaction is carried out in a slightly negative, near neutral or slightly positive pressure.

The injection of carbonaceous material and oxygen into the bath, along with the stirring induced by its reaction, will produce an area of foamy slag or froth in the freeboard area above the molten bed. The froth can contain iron oxide (FeO), molten iron particles, silicon dioxide, carbon particulate, fuel gas and small amounts of carbon dioxide. This creates a second zone of high temperature activity providing the opportunity for additional production of synthesis gas. This is possible in part due to the notable increase of available reaction surface area provided by the froth. Therefore, additional controlled injection of carbon and hydrocarbon material with oxygen and other reactive gases into this froth region will enhance the production of synthesis gas. Specific flow patterns and flow mixing in this froth reaction zone are induced by the integrated injector system to increase synthesis gas production. This froth reaction can become quite large, filling the entire freeboard area of the furnace and consequently flowing out the exhaust plenum. Therefore, a third controlled injection region, called the off-take zone, at the top of the furnace freeboard area is provided with carbon or hydrocarbon injection to create a barrier to froth growth by depleting the FeO presence and creating a thermal barrier.
The following description of the preferred embodiment is merely exemplary in nature and is not intended to limit the invention, its application or uses.

In FIG. 1 there is shown a partial sectional view of a gasifier that includes an injector system in accordance with a preferred embodiment of the present invention. The injection system consists of a single, center main injector lance 1, one or more top perimeter injector lances 2, one or more side injector lances 3, one or more bottom injector lances 4 and one or more freeboard injection lances 2a. Each injector lance has its own mounting and positioning clamp mechanism 5 represented as 5a through 5e, respectively.

Center main injector lance and center main injection lance refer to a lance that extends substantially along a central, longitudinal axis of a vessel, such as a gasification reactor.

Top perimeter injector lance or top perimeter injection lance refer to a lance that extends substantially alongside at least a portion of a center main injector lance.

Side injector and side injection lance refers to a lance that extends through a sidewall of a vessel, such as gasification reactor.

A bottom injector lance and bottom injection lance refer to a lance that extends into a molten metal through the bottom of the vessel, such as a gasification reactor, and introduces one or more feed materials directly into the molten metal. A freeboard injector lance and freeboard injection lance refer to a lance that extends substantially alongside at least a portion of a center main injector lance or top perimeter lance. Freeboard lances are considered as a subset of the category top perimeter lance.

The feed streams for each lance can vary, consisting of solids, liquids and gases in various combinations designed to maximize the production of synthesis gas. The center main lance feed stream 6 is typically the largest solids feed throughput. As shown in FIG. 3, the center main lance is capable of tip injection at 27 and 28 at subsonic, sonic and supersonic velocities as well as simultaneous subsonic or sonic injection of liquids, solid fines or gases through injector ports located in the sidewall of lance 1. The top perimeter lances 2 are capable of injecting a feed stream 7 consisting of solids, liquids, gases or combinations thereof.
at subsonic, sonic and supersonic tip injection velocities. Top perimeter lances 2 are also capable of simultaneous subsonic or sonic injection of liquids, solid fines or gases through injector ports located in the sidewall of lance 2. The side injector lances 3 inject feed material tangentially through the sidewall of a molten metal gasification reactor 11. The side injector lances 3 are capable of injecting a feed stream 8 consisting of solids, liquids, gases or combinations thereof, at subsonic, sonic and supersonic tip velocities. The bottom injector lances 4 are capable of injecting a feed stream 9 consisting of gases and solids or gases only at subsonic tip velocities. The freeboard injection lances 2a are capable of injecting fine solid material, liquid or gaseous material at subsonic or supersonic speed through the sidewalls of lance 2a.

The injection system is configured to control the gasification reaction throughout the gasification reactor or gasifier 11. In FIG. 1 the reactor 11 is composed of a molten metal bottom section 10 configured to hold a molten metal 16 and a slag layer 17, an extended freeboard area composed of a secondary froth reaction zone 18 and an off-take zone 19, with a top flange connection 13 supporting a lid 12. Lid 12 has injection lance entry points with seals for center main injector lance 1, top perimeter injector lances 2, freeboard injector lances 2a, and an exhaust plenum 14. Gasification reactor 11 is also equipped with one or more devices 11a to measure the temperature in the reactor, two or more cameras 11b mounted in lid 12 to record optical and infrared signatures of the reaction volumes, one or more acoustic sensors 11e to record vibration activity and one or more devices 11d to measure the synthesis gas composition. Exhaust plenum 14 allows exit of a synthesis gas 15 at the proper velocity and pressure. In some configurations, exhaust plenum 14 has one injector lance entry port with a seal for center main injector lance 1, thus eliminating the need for a center main entry port and seal on lid 12.

A variety of molten bed furnaces can be utilized with the injector system of the present invention. Induction furnaces are preferred, but not necessary, because they can be configured to induce a stirring and mixing motion in the molten bed which enhances the gasification reaction driven by the injector system.
FIG. 2 illustrates a cross section of a gasification reactor or gasifier that is suitable for use with the injector system of the present invention showing the chemical reactions that take place therein during a gasification reaction of a carbonaceous fuel. Oxygen is introduced into a molten metal 16 by means of one or more oxygen lances. As the oxygen impinges on molten metal 16, which initially consisted of iron, carbon and silicon, the oxygen initially oxidizes the iron to iron oxide as follows:

\[ 2 \text{Fe} + \text{O}_2 \rightarrow 2 \text{FeO} \]  \hspace{1cm} (1)

The silicon dissolved in molten metal 32 is then oxidized to silicon dioxide as follows:

\[ \text{Si} + 2\text{FeO} \rightarrow \text{SiO}_2 + 2\text{Fe} \]  \hspace{1cm} (2)

Likewise, the carbon dissolved in molten metal 32 is then oxidized to carbon monoxide as follows:

\[ \text{C} + \text{FeO} \rightarrow \text{CO} + \text{Fe} \]  \hspace{1cm} (3)

The oxidation of the iron to iron oxide and silicon to silicon dioxide involves minimal volumetric change. However, as the carbon is oxidized to carbon monoxide, there is a significant increase in volume when a solid is oxidized to a gas. This volumetric expansion causes molten metal 16, the liquid iron oxide, the liquid silicon dioxide and a slag 17 to form a molten metal froth 18.

If the carbon is not replenished, the oxygen will remove virtually all of the carbon in molten metal 16 in about fifteen minutes. Thereafter, froth 18 will collapse and the iron will be completely oxidized to iron oxide. To maintain froth 18 and molten metal 16, the carbon must be injected at a rate equal to the rate at which the carbon is being removed by oxidation, as follows:

\[ \text{FeO} + \text{C} \rightarrow \text{CO} + \text{Fe} \]  \hspace{1cm} (4)

This insures that the iron that was oxidized to iron oxide is then subsequently reduced by the carbon returning most of the iron to molten metal 16 so that it can subsequently be re-oxidized thereby allowing the cycle to repeat indefinitely. This continuous recycling is important to the efficiency of the process. Since some of the iron oxide will be carried out of the gasification reactor as part of slag 17, there will be a depletion of molten metal 16. Consequently, the iron will have to be added to
the gasification reactor to maintain the required level of molten metal 16 in the
gasifier.

As carbon in the form of a solid carbonaceous fuel is injected into molten
metal 16, some of it will dissociate into the carbon and hydrogen and some will
remain as a hydrocarbon. Likewise, as a liquid or a gaseous carbonaceous fuel is
injected into froth 18, slag 17 or molten metal 16, some of it will dissociate into
carbon and hydrogen and some will remain as a hydrocarbon. That portion of the
carbonaceous fuel that dissociates will cause molten metal 16 to froth as the
hydrogen is released as a gas. To dissociate the fuel, heat must be provided, as
follows:

\[
\text{Carbonaceous Fuel} + \text{heat} \rightarrow \text{C} + \text{H}_2 \quad (5)
\]

Likewise, that portion of the carbonaceous fuel that is oxidized to carbon monoxide,
carbon dioxide and water vapor by the oxygen will cause molten metal 16 to froth.

\[
\text{Carbonaceous Fuel} + \text{Oxygen} \rightarrow \text{Synthesis Gas} \quad (6)
\]

\[
2\text{C} + 2\text{H}_2 + 2\text{O}_2 \rightarrow \text{CO} + \text{CO}_2 + \text{H}_2 + \text{H}_2\text{O} + \text{Heat} \quad (6a)
\]

The frothing process is most important since it increases the surface area for the
following reaction.

\[
\text{Carbonaceous Fuel} + \text{Iron Oxide} \rightarrow \text{Synthesis Gas} \quad (7)
\]

\[
2\text{C} + 2\text{H}_2 + 4\text{FeO} \rightarrow \text{CO} + \text{CO}_2 + \text{H}_2 + \text{H}_2\text{O} + 4\text{Fe} + \text{Heat} \quad (7a)
\]

The amount of oxygen added is closely controlled so that the heat released
will provide the heat to dissociate the carbonaceous fuel and provide the heat
required to elevate the synthesis gas to a temperature high enough to keep froth 18,
slag 17 and metal 16 molten. The operating temperature will be in the range of
2700 to 3000°F.

The resulting synthesis gas consists of carbon monoxide, carbon dioxide,
hydrogen and water vapor. The ratio of the products in the synthesis gas is
controlled by the following equilibrium:

\[
\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2 \quad (8)
\]
The equilibrium constant for equation 7 is equal to:

\[ k = \frac{[pCO_2 \times pH_2]}{[pCO \times pH_2O]} = \frac{[6355 \div (-R \times T)]}{[6.24 \div (-R \times T)]} \]

(9)

Where \( p \) = Pressure

\( R \) = Gas Constant

\( T \) = Temperature

Since the equilibrium constant \( k \) is temperature dependent, the percentage of each gas will vary with temperature. The higher the temperature the greater the amounts of carbon monoxide and water vapor. Conversely, the lower the temperature, the greater the amounts of carbon dioxide and hydrogen. The ratio of carbon compounds formed to the hydrogen compounds formed is directly proportional to the amount of carbon and hydrogen in the carbonaceous fuel.

The gasification reactor is maintained under either a slightly negative, neutral or slightly positive pressure to remove the hot synthesis gas via an exhaust plenum while maintaining the proper reaction and diffusion of gases from molten metal 16 and slag 17. The exhaust plenum is refractory lined since the synthesis gas exits at temperatures as high as 2700 to 3000T.

Because the carbonaceous fuel may contain some metallic elements, they oxidize and become part of slag 17 or molten metal 16. When these metal oxides cause slag 17 to go basic, silica sand can be added to keep slag 17 fluid. Conversely, when these metal oxides cause slag 17 to go acidic, dolomitic limestone can be added to lower the melting point of slag 17 to keep it fluid. It should be noted that slag chemistry in this process is important as it relates to the viscosity of slag 17 and the necessity of controlling the continuity of the synthesis gas production. In addition, just as in a metal refining process, the chemistry of slag 17 is related to the removal of detrimental impurities. In the synthesis gas production, it is advantageous to keep any impurities, such as sulfur and phosphorous, in metal bath 16 or capture these impurities in slag layer 17 rather than having to remove them from the gas stream in some later step. The slag chemistry is monitored by periodic sampling and computer control. A siphon type slagger can be employed to continuously remove excess slag 17. Most heavy
metals, if present in the feed stream, can also be captured by the molten metal or slag regimes.

The following paragraphs now explain certain features of each major hardware section of the injector system of the invention.

**Main Center Lance Injection System**

Center main injector lance 1 is a multiple tube lance entering from the top along the centerline of molten metal gasification reactor 1I (see FIG. 1). As shown in FIGS. 1 and 3, this lance is composed of a lance housing 20, a main center feed tube 21, one or more auxiliary injection tubes 22, a material distributor 23, one or more froth zone injection tubes 24, one or more off-take injection tubes 25, a copper injection tip 26 and center main lance clamping, sealing and positioning mechanism 5a.

As depicted in FIGS. 3 and 4, this main center lance injection system distributes center main lance feed stream 6 into specific custom feed streams with the following primary features:

i) Injection of solid carbonaceous fuels and reaction gas through injector tip 27 directly into molten metal 16 (or other gasifier material) through center main feed tube 21.

ii) Injection of reaction gas or liquid carbonaceous fuels through injector tip 28 directly into molten metal 16 through auxiliary injection tubes 22.

iii) Injection of gas or liquid carbonaceous fuels through injector tip 29 directly into secondary froth zone 18 from froth zone injection tube 24.

iv) Injection of gas or liquid carbonaceous fuels through injector tip 30 directly into off-take zone 19 from off-take injection tube 25.

v) Multiple tube quantities and locations within each injection lance.

vi) Solids, gases or liquids can be injected.

vii) Variable injection velocities for tip injection and perimeter side injection can be generated.

viii) Real-time variable stand-off distances from lance tip to molten metal 16 can be achieved.
ix) Generation and control of vertical stirring and mixing by variation of tip injection velocity and stand-off distance.

x) Generation and control of perimeter reaction area and volume.

xi) Counter turbulent flow injection into secondary froth reaction zone 18 or off-take zone 19.

xii) Cyclonic flow injection into froth reaction zone 18 or off-take zone 19.

xiii) Generation and control of horizontal plane stirring direction, speed and mixing by varying material flow through side injector tip 29 into froth reaction zone 18 to improve synthesis gas 15 production efficiency and output. As shown in FIG. 4, a solid carbonaceous fuel injection 31 into molten metal 16 (or other gasifier material) is accompanied with a primary reaction gas injection 32, at a controlled tip velocity and stand-off distance 34 to facilitate proper depth of penetration and stirring action 33. This control is needed to maintain a balanced iron (Fe) - carbon (C) reaction within the proper region of the Fe-C equilibrium chart and to insure all the metal required for reaction is fully exposed to the injected material. The reaction gas exiting injector port 27, serving simultaneously as the solid carbonaceous fuel material carrier gas, can be oxygen, carbon dioxide steam or other gaseous materials depending upon the thermodynamics of the reaction and the heat value of the solid material being injected. This solid material and reaction gas balance is kept within the proper range to facilitate an exothermic reaction, resulting in maximum efficiency.

The injection of reaction gas or liquid carbonaceous fuel exiting injector tip 28 from auxiliary feed tubes 22 can be configured to support molten metal 16 penetration and/or injection directly above molten metal 16 through injector tip 29 in froth zone 18, depending upon the desired result. The tip feed streams exiting injector tips 28 can be used to supply additional reaction gases (if needed) to support the exothermic reaction induced by the feed stream exiting injector tip 27 or to enhance the production of synthesis gas 15 within secondary froth zone 18. Auxiliary injection tubes 22 can also help establish the proper turbulence within molten metal 16 to maximize solid material mixing and hence increase synthesis gas 15 production. The combined momentum (tip velocity multiplied by total flow
mass) of the feed stream traveling through main center feed tube 21 and exiting through injector tip 27 and the feed stream traveling through auxiliary injection tubes 22 and exiting through injector tips 28 are individually controlled to facilitate the proper amount of vertical stirring and mixing of molten metal 16, slag within slag layer 17 and froth within froth reaction zone 18. This is accomplished by adjusting to the proper stand-off distance 34 for the given mass flow parameters as well as by adjusting the mass flow rates based upon feedback information. These adjustments, as shown in FIG. 4, determine the size of the reaction volume created by solid carbonaceous fuel injection 31 for the feed stream exiting injector tip 27 and the reaction volumes created by primary reaction gas injection 32 for the feed streams exiting injector tips 28. In this way, the optimum reaction condition can be maintained at each penetration despite variations in feed stream content. The number and location of the auxiliary feed tubes 22 can vary according to the injection reaction desired. Tap holes can be provided for additional feed through ports as needed.

The perimeter side port injection through injector tip 29 by the center main injector lance 1 of gas or liquid into secondary froth reaction zone 18 is one of several precise controls utilized to tune the froth reaction for maximum synthesis gas 15 output. Turbulent opposing flow or cyclonic flow of reactive materials in froth reaction zone 18 can be facilitated using this perimeter injection feature. The perimeter side injection through injector tip 30 of gas or liquid into off-take zone 19 is one of the primary means of controlling the vertical growth of froth reaction zone 18. This perimeter side injection through injector tip 30 is designed to produce a thermal cloud or "lid" effect to top-off or prohibit the vertical migration of molten metal froth material from entering lid 12 and exhaust plenum 14. The location of off-take injection tube 25 can also be used to efficiently gasify certain feed stream gases or liquids that would not support proper reaction if fed into gasification reactor 11 at another location.

**Top Perimeter Lance Injection System**

This is a multiple-lance injection system, each lance with multiple tubes. The system is sized in lance and tube diameter to supplement, center mail injector
lance 1 by providing molten metal reaction regions 35 around the perimeter of the reaction volumes created by solid carbonaceous fuel injection 31 and primary reaction gas injection 32 as shown in FIG. 5. The configuration of four top perimeter lances shown in FIG. 5 is only one of several options. Two, four, six, eight or more top perimeter injector lances 2 can be configured through lid 12 of gasification reactor 11, depending upon the size and shape of each perimeter reaction volume and the extent of vertical stirring action 33 required. As depicted in FIG. 6, top perimeter lance 2 is composed of a lance housing 36, a primary center feed tube 37, one or more auxiliary feed tubes 38, a material distributor 39, one or more froth zone injection tubes 40, one or more off-take zone injection tubes 41, a copper injector tip 42 and clamping, sealing and positioning mechanism 5b.

Top perimeter lance injector lance 2 distributes top perimeter lance feed stream 7 into specific individual feed streams in support of the desired total reaction. Top perimeter lance injector lance 2 can be configured identically to that shown for center main injector lance 1 in FIG. 3. In this configuration, top perimeter injector lance 2 is sometimes smaller in diameter with fewer auxiliary feed tubes 38. Alternatively, top perimeter injector lance 2 can be configured as shown in FIG. 6a. This alternative configuration utilizes an offset primary feed tube 37a for solid carbonaceous fuels and a carrier gas feed 43a combined with one or more auxiliary feed tubes 38a for gas or liquid only reaction feed 44a. In addition, this alternative configuration can be outfitted with one or more froth zone injection tubes 40a and one or more off-take zone injection tubes 41a.

Top perimeter injector lance 2 has the following primary features:

a) Solid carbonaceous fuel material and carrier gas feed stream 43 tip injection into molten metal 16 (or other gasifier material) through primary feed tube 37.

b) Reaction gas or liquid feed stream 44 tip injection through auxiliary injection tubes 38. Injection can be into molten metal 16 (or other gasifier material) or into secondary froth reaction zone 18 depending upon lance positioning.

c) Gas or liquid perimeter feed stream 45 side injection into secondary froth reaction zone 18 through froth zone injection tubes 40.
d) Gas or liquid perimeter feed stream 46 side injection into off-take zone 19 through off-take zone injection tube 41.
e) Multiple lance locations around the perimeter of lid 12.
f) Multiple tubes quantities and locations per injection lance.
g) Solids, gases or liquids can be injected.
h) Variable injection velocities for tip injection and perimeter side injection can be generated.
i) Real-time variable stand-off distances can be achieved.
j) Generation and control of vertical stirring and mixing 33.
k) Generation and control of molten metal reaction regions 35.
l) Counter turbulent flow injection into secondary froth reaction zone 18 or off-take zone 19.
m) Cyclonic flow injection into the froth reaction zone 18 or off-take zone 19.
n) Generation and control of horizontal plane stirring direction, speed and mixing in froth reaction zone 18 to improve synthesis gas 15 production efficiency and output.

Solid carbonaceous fuel material and carrier gas feed stream 43 tip injection into molten metal 16 (or other gasifier material) can be accomplished with the primary reaction gas (or a secondary reaction gas) at a controlled tip velocity and stand-off distance 34. This not only facilitates proper depth of penetration and stirring action, but also provides variations in gas input to help maintain the proper range of exothermic reaction. The reaction gas, serving simultaneously as the transfer or carrier gas, can be oxygen, carbon dioxide, steam or other gaseous material, depending upon the thermodynamics and desired reaction. Other key parameters which influence top perimeter lance injection include the size and volatility of the solid carbonaceous fuel injection 31, the heat value of the solid material and the amount and type of transfer gas utilized by the main center feed tube 21. Each top perimeter injection lance is matched in part to the size and characteristics of solid carbonaceous fuel injection 31 and primary reaction gas injection 32 in order to utilize all the available molten metal 16 in the gasification reactor 11. The number and extent of molten metal reaction volumes 35 is also
driven by the available surface area of molten metal 16. Depth of penetration, tip velocity, stand-off distance, mass flow rates and feed streams momentum are all variable to allow maximum adjustment capability in order to maintain improved synthesis gas production for a widely varying feed stream.

The reaction gas or liquid tip injection -4 through auxiliary feed tube38 can be configured to support molten metal 16 penetration or froth reaction zone 18 injection directly above the surface. Tip injected feed streams 43 and 44 can provide additional reaction gases (if needed) to supplement or enhance the center main lance reactions 31 and 32. This same tip injection capability can be used in the secondary froth reaction zone 18 or off-take zone 19 by simply retracting top perimeter lance housing 36 until the tip is properly positioned in the desired reaction zone as illustrated in FIG. 7. In this case, the side perimeter injection ports are closed off.

Top perimeter injector lance 2 also provides the option for simultaneous gasifier material injection and froth or off-take zone injection as shown in FIG. 5. The perimeter side injection gas or liquid feed streams 45 and 46 maximum capacity for froth reaction zone 18 and off-take zone 19 is typically less than the same capacity for the feed streams exiting injector tips 29 or 30, due to their closer proximity to the refractory lining. However, having less volume to feed, this capability provides even further precise control of the froth reaction and off-take reaction for maximum synthesis gas production. Liquid or gaseous fuel injection in off-take zone 19 is critical to froth reaction zone 18 growth control as previously discussed.

Control of the flow direction from froth zone injection tubes 40 and off-take injection tubes 41 is very important to achieving the proper control (or disruption) of stirring direction and mixing in secondary froth reaction zone 18. For more volatile fuel types, it is usually necessary to achieve uniform flow in one direction to stabilize and concentrate the reaction and its vertical growth in froth reaction zone 18. However, in some cases, more volatile fuels can benefit from opposing upper level and lower level flows in gasifiers with or without a solid material reactant. FIG. 8 is an example of opposing upper and lower level cyclonic flow
patterns in froth reaction zone 18. For uniform flow in one direction, a cyclonic effect can be achieved in secondary froth reaction zone 18. This effect creates an optimum stirring, concentration, and mixing of the fuel and transfer gas constituents along the inside perimeter or circumference of gasification reactor 11. The less volatile, internal center of the cyclonic flow also provides a calmer region for center main injection lance 1. This uniform cyclonic flow also enhances the upward flow of hot synthesis gas 15 while facilitating the dropping of solid particulates back down into gasification reactor 11. For less volatile or reactive fuels, it is sometimes necessary to induce opposing flows in froth reaction zone 18 in order to stimulate stirring, mixing and reaction magnitude and rate. This can be achieved by various opposing flow injection schemes as illustrated in FIG. 9. The versatility of the design allows virtually an infinite number of combinations of rotational flow and turbulent flow for different port locations and lance positioning. Key parameters in creating efficient froth reaction zone 18 flow dynamics include vertical positioning of top perimeter injection lances 2 in gasification reactor 11, varying the number of top perimeter lances used, varying the number of perimeter side injection ports in each lance, varying the flow direction and velocity of each side injection port, and varying the rotational positioning of top perimeter lance in the mounting device.

With a widely varying, complex feed stream, these various injector system configurations can be tested easily and quickly. This permits the builder to find the empirically optimum design for the specific customer feed stream characteristics and requirements. In addition, if the desired feed stream characteristics change over time, the system is versatile enough to be re-configured to a new optimum design configuration without costly hardware modifications or additions.

**Side Lance Injection System**

This is a multiple lance injection system, each lance with multiple feed tubes. The system is sized in lance and tube diameter to compliment center main injection lance 1 and top perimeter injection lances 2 for gasification reactor 11. There are also conditions, such as certain all liquid feed streams, where side injection lances 3 can operate independently from the other injection systems as required. In addition to providing important feed stream injection capability to the
lower portion of gasification reactor 11, side injector lances 3 are designed to facilitate horizontal rotational stirring control of molten metal 16 and slag layer 17, basically in the plane of the surface of molten metal 16. This capability is critical to achieving maximum mixing of the feed stream constituents with all the available molten metal 16 and slag layer 17. Side injection lances’ 3 stirring control is actually manifested in both the horizontal and vertical directional planes at the bottom of gasification reactor 11. The side lance injection system 3 can actually be a single side mounted lance, or multiple side mounted lances, depending upon the types of feed stream materials, the size of the gasification reactor and the desired gasification, stirring and mixing reaction characteristics. The example configuration of two side injectors shown in FIG. 10 is only one of several options. The side lance injection system can be configured exactly like the tip injection configurations shown in FIG. 3 or the tip injection systems shown in FIG. 6 or FIG 6a. There can be perimeter side port injection options upward or downward into the froth zone. The side lance injection system is composed of a lance housing, a center or primary feed tube, auxiliary feed tubes, clamping, sealing and positioning mechanism 5c, and a copper tip.

The side lance injection system has the following primary features:

a) Processes solids, liquids or gases.

b) Multiple lance locations on circumference of gasification reactor.

c) Multiple tube configurations per lance.

d) Variable tip injection speed and mass flow rates.

e) Variable stand-off distances in real time.

f) Generation and control of stirring and mixing in the vertical and horizontal directions.

g) Generation and control of side reaction zone volume.

h) Variable vertical impingement angle as shown in FIG. 11.

i) Variable side entry angle as shown in FIG. 10.

The solid material injection is accomplished with the primary reaction gas (or a secondary reaction gas) at a controlled tip velocity, mass flow rate, side entry angle, vertical impingement angle and stand-off distance. This not only provides
proper depth of penetration, control of rotational flow direction, control of reaction area and volume, control of stirring and mixing action, but also allows variations of gas input to maintain the proper range of exothermic reaction. Due to the proximity with the bottom of the gasification reactor, and the inherent versatility in positioning and angles of injection, the side lance system 3 is often used for liquid feed stream injection. Transfer or carrier gases and reaction gases injected can include oxygen, carbon dioxide, steam or other hydrocarbon gaseous material, depending upon the thermodynamics desired and the material injection characteristics of the other operating lance systems. Depth of penetration, tip velocity, stand-off distance, mass flow, momentum rate are all variable to allow maximum adjustment capability for the overall gasification reaction.

Secondary reaction gas or liquid can be injected through the auxiliary feed tubes as required by the particular feed stream characteristics, and the integrated gasification reaction. For example, when injecting a liquid stream, a separate reaction gas injection tube can be provided to create the deformation region in the molten metal resulting in the turbulent flow necessary to insure complete liquid penetration and mixing. The auxiliary feed tubes can also be easily plugged to protect from metal or slag material impingement when reaction gas injection is not required.

**Bottom Lance Injection System, Item**

This is a multiple lance injection system with each lance capable of housing multiple feed tubes. The system is sized to operate alone, or in conjunction with any combination of the other four injection systems. Injection at this point guarantees complete penetration of any molten reactant material.

With or without molten metal reactant material, bottom injection maximizes residence time in gasification reactor 11. In addition, for a molten material gasifier 11, bottom injection allows processing of additional volatile feed material that would cause too much stirring and turbulence in the molten material if injected through the top or sides of the gasification reactor. As with the side injection system, the bottom injection system can be a single lance 4 or multiple bottom injection lances 4 configuration depending upon the types of feed material, the size
of the gasification reactor and the desired characteristics for the stirring, mixing and
thermodynamic reaction. The example configuration of two bottom injectors
shown in FIGS. 1 and 11 is only one of several options. Bottom injection lances 4
can be configured like the side lance injection system of FIG. 3 or FIGS. 6 and 6a,
noting that there are no perimeter side tube injectors. Bottom injection lances 4 are
composed of a lance housing, a center or primary feed tube, auxiliary feed tubes, a
material distribution, and clamping, sealing and positioning mechanism 5d.

The bottom lance injection system has the following primary features:

a) Processes solids, liquids and gases.
b) Multiple lance locations on the bottom section of the gasification reactor.
c) Multiple tube quantities per lance.
d) Variable tip speed and mass flow rate.
e) Generates and controls vertical and horizontal stirring and mixing in the
   bottom of the gasifier.
f) Generates and controls bottom reaction zone volume,
g) Variable angle of entry.

Solid material injection is accomplished with primary reaction gas (or a
secondary gas) at a controlled tip injection mass flow rate, entry angle and
penetration distance. This not only allows for enhancement of vertical and
horizontal stirring and mixing but also facilitates full utilization of the available
molten metal 16 or other reactant material in the horizontal and vertical dimensions
of gasification reactor 11. As noted in FIGS. 10 and 11, variable entry angles can
be achieved with one unit. In FIG. 11, the bottom reaction volume plumes outward
as it rises through molten metal 16. The same phenomenon holds for bottom
injection without molten metal 16. This is due to the natural outward injection flow
induced by most bottom injection lances 4. The plume effect can be attenuated to
some degree by changing the injection port directions and/or eliminating the center
feed tube when the particular reaction calls for a narrower, vertical reaction volume.
Variations in gas input are also available to insure the proper combined reaction to
sustain controlled exothermic conditions. Gas injection can include oxygen, carbon
dioxide, steam or other hydrocarbon reaction gases depending upon the
thermodynamics required. Depth of penetration, angle of entry, and mass flow rate
are all variable to maximize the adjustment capability for the overall gasification
process. Secondary gas or liquid can be injected through the auxiliary feed tubes as
required by the integrated gasification reaction. The auxiliary feed tubes can also
be easily plugged to protect them from flow through when material injection needs
to be limited to the
center feed tube.

**Freeboard Injection System**

This is a multiple lance injection system specifically configured for injection
into the froth zone and off-take zone. Together, these zones are referred to as the
freeboard area. The freeboard injection lances 2a are another set or type of top
perimeter lances. Each lance 2a is capable of housing multiple feed tubes.  
Freeboard injection lances 2a do not utilize tip injection into the molten metal or
slag. The system is sized to operate alone, or in conjunction with any combination
of the four injection systems (center main inject or lance 1, top perimeter injection
lances 2, side injection lances 3 and bottom injection lances 4). The role of the
freeboard lance injection system is unique in that it can supplement froth reaction
zone 18 and off-take zone 19 injection from the side wall injection exiting injector
tips 29 and 30, and the top perimeter lance 45 and 46, or it can totally and
independently control froth reaction zone 18 and off-take zone 19 injection process
when the center main or top perimeter lance sidewall injections are not available or
not appropriate. The configuration of three freeboard injection lances 2a is shown
in FIG. 12. Varying numbers of freeboard lances can be used from one to as many
as eight or more in a single reactor, depending upon the size of the reactor, the top
perimeter injection lance configurations and the required feed stream characteristics
and throughput.

As shown in FIG. 12, each freeboard injection lance 2a is composed of a
lance housing 47, a feed tube 48, one or more straight flow side port injector
nozzles 51a, and one or more angled flow side port nozzles 51b.

Each freeboard injection lance 2a has the following primary features:
a) Injection via a single or multiple stream of vertical ports, at a wide range of injection velocities, densities and mass flow rates

b) Ability to rotate the freeboard lance within its mounting structure in real-time to modify flow direction, flow pattern effects, stirring and mixing

c) No distributor which allows greater concentration of flow in a single direction for enhanced freeboard area injection effect

d) Creation of greater opposing turbulent flow effect allows reaction of certain non-volatile feed streams in the freeboard area as shown in FIG. 13

e) Presence of stronger directional flow effect increases ability to create multiple levels of opposing cyclonic flow as shown in FIG. 14

f) Variable injection velocity and mass flow rate based upon feedback

   Primary feed stream 49 can be a finely ground solid, a liquid or a gas. If a finely ground solid is used the primary feed stream will also contain a carrier gas which acts as the reaction gas. If the fine solid and carrier gas cannot be mixed in the same injection line, then a separate feed tube is added to the configuration for the reaction gas.

   With this versatility, multiple reaction characteristics can be achieved in the froth reaction zone 18 and the off-take zone 19. For example, as shown in FIG. 14, multiple levels of opposing cyclonic flow 52a, 52b, 52c, can be achieved within the froth reaction zone 18. This mixing pattern is particularly useful for less volatile feed streams which need flow concentration and cross mixing to achieve full reaction potential. Multiple levels of parallel cyclonic flow can also be achieved when flow concentration is needed without cross mixing. In addition, various forms of opposing turbulent flow, as shown in FIG. 13 can be achieved. Center focused turbulent flow 53 fills the center of the froth reaction zone 18 with a concentrated reaction for situations where the center main froth injection exiting injector tip 29 or the top perimeter froth injection feed streams 45 are weak or nonexistent. Perimeter focused turbulent flow 54 concentrates reaction in the perimeter region when center main froth injection exiting injector tip 29 or top perimeter froth injection feed streams 45 are focused toward the center of froth reaction zone 18. These and many variations in flow pattern direction, concentration and mixing can
be achieved and adjusted in real-time simply by coordinated rotation of the top perimeter lances and the freeboard lances within their respective mounting mechanisms. With a widely varying, complex feed stream, these variations in injection can be tested easily and quickly. This permits the designer to find empirically optimum configurations for the specific feed stream characteristics of the customer or end user. It also allows real-time adjustments in the configuration to compensate for changes in the feed stream characteristics in order to maintain near optimum gasification efficiency.

Secondary Reaction Froth Region

As previously discussed, during the injection of hydrocarbon material and oxygen into molten metal 16, it is common to experience a foamy slag or frothing and fine material expansion above molten metal 16 and slag layer 17. The purpose of injection into froth reaction zone 18 is to create a controlled secondary gas reaction and controlled froth stirring which provides the following features:

i) Allows complete gasification of any hydrocarbon particulates not fully reacted in the molten metal gasification section.

ii) Facilitates the introduction of additional hydrocarbon fines and reaction gases to allow additional gasification reaction and boost synthesis gas production. These fines can include coal, spent tires, waxes, waste oils, industrial waste chemicals, and bio-solids.

iii) Permits secondary injection of by-products and waste gases (see Table 1) to accelerate and expand synthesis gas formation.

iv) Permits secondary injection of gaseous reactants such as oxygen, CO₂ or water vapor to control and enhance temperature levels and H₂ and CO formation.

v) Maximizes the contact of slag with metal. Contaminants such as sulfur and chlorine are best removed at the slag metal interface. Controlled stirring improves this process.

vi) Controlled stirring also provides the best opportunity to maintain uniform foamy slag throughout the freeboard area, which maintains slag consistency and improves slag tapping efficiency.
Expandable Off-Take Zone

Injection into the off-take zone 19 allows control of the height and intensity of froth reaction zone 18 and provides a stable transition of the expanding synthesis gas into lid 12 and exhaust plenum 14. For some feed stream conditions, the height and extent of froth reaction zone 18 can grow too rapidly and interfere with the controlled synthesis gas production and transition into lid 12 and exhaust plenum 14. Therefore injection into off-take zone 19 is provided to allow injection of pure light gases, oxygen, carbon dioxide, or water vapor to create a hot spot (or cold spot) which will place a controlled cap or limiter to the upper extent of froth reaction zone 18. Care must be taken not to inject too much oxygen or carbon/hydrocarbon material into off-take zone 19, resulting in excessive depletion of froth reaction zone 18. This is accomplished by real time analysis of the digitized data from a two color optical camera and from an infrared camera. As a result, injection into off-take zone 19 is often an intermittent process, occurring only long enough to keep froth out of exhaust plenum 14. This "capping" or stopping of froth reaction zone 18 vertical expansion is important to the overall efficiency and control of the gasification process. This area is topped by a flanged connection to lid 12 which allows design expansion of froth reaction zone 18 and off-take zone 19 due to changes in the feed stream characteristics or quantity, as well as changes in the thermal conversion process. This is accomplished simply by the addition of one or more refractory lined circular sections between off-take zone 19 and lid 12. Injection into off-take zone 19 also provides an additional "pure injection" zone for certain gaseous materials available from waste by-products, landfills, Fischer Tropsch by-products and digesters as outlined in Table 1.

Lance Sealing and Positioning

The sealing of each lance is based upon three temperature zones designed to accommodate the requirement for a continuous, tight seal during lance movement, without having to shut down the primary gasification reactor. A different sealing and insulation material is used for each temperature zone. As seen in FIG. 15, a ceramic fiber or other flexible, high temperature material is used in the first seal zone 53. This material provides the combined high temperature resistance and tight
packing characteristic needed for the close proximity to the free board gaseous area. Sometimes a supporting refractory structure 54 is used to hold the seal material 53 in place during downward motion of an injector lance (1, 2, 2a or 3) toward molten metal 16. A second seal zone 55 utilizes a harder seal material with a horizontal spring-loaded center 56 which creates a tight seal in the presence of a moving lance interface. A third seal zone 57 is composed of a ceramic fiber or other material to provide both a thermal insulation and a lance wall seal interface while supporting and sealing off a vertical spring 58 and a load pads 59. Vertical spring 58 maintains compression on load pads 59 which hold sealing materials 53, 55, and 60 in place during vertical motion of lanes 1, 2, 2a and 3. A third sealing zone 60 is composed of a synthetic based material which provides sealing capability at the lower temperatures present in this third zone. This third seal zone also incorporates a horizontal spring loading to secure the material in place.

In this way, the type of seal design and material composition is properly matched with the thermal region being sealed. By staging the seal design and material to the temperature zone levels, the best combination of seal material and thermal insulation material can be utilized for the integrated design.

As previously noted, the movement of each lance during gasification reactor 11 operation is important to the real-time tuning of the gasification process. In this design, the lances can be moved upward or downward in increments by the utilization of an angled, inclined stairway approach. The total upward or downward movement can be sized to accommodate the vertical dimension of the free board area. The stair-step increment can be tailored to the required precision for each application, including incremental steps less than one inch each.

As shown in FIG. 16, a lance positioning mechanism is composed of two primary sections, a fixed section 61 and a floating section 62. The floating section fits on top of the fixed section when the unit is assembled. Fixed section 61 includes a base flange 63 mounted to a sealing section flange. The fixed section also includes pin slots 64 in metered increments along the top edge of front and back stanchions 65 and 66. Floating section 62 includes front and back stanchion pieces 67 and 68 with a positioning pin 69 at the base of each stanchion. The
floating piece also includes a lance seat 70, the underside of which sits on the upper edge of the fixed section 61. Lance seat 70 supports the inserted lance along the lance flange. The floating section also includes a worm gear and bearing unit 71 mounted to front stanchion 67 and lance seat 70. The worm gear and bearing unit is driven by a positioning motor 72.

Beginning in the full down position of FIG. 16, the inserted lance is lifted upward as shown by the dotted lines of FIG. 16. The positioning motor then turns the worm gear and bearing unit which lifts and rotates the floating section upward, removing positioning pins 69 from pin slots 64. The positioning motor continues to rotate and move the floating section upward until positioning pins 69 engage with appropriate new pin slots 64. The lance is then lowered down on to lance seat 70. Once the floating section is removed from its fully down position, this positioning process can be repeated in both directions, thus allowing the lance to be re-positioned in given increments anywhere along the run of the stanchion edges. If the positioning motor 72 fails, the floating section can be manually positioned using a positioning handle mount 73.

The preferred embodiments of the present invention can inject and gasify a large array of mixed wastes and fuels from domestic and industrial applications. These wastes and fuels can be contaminated with a variety of in-organics and hazardous materials. Thus, the present invention allows for versatility and adaptability of design to accommodate a variation of organic and in-organic material and still achieve high efficiency in synthesis gas production. However, this same versatility and adaptability of design implementation can be very useful in other applications and embodiments.
Claims

Having set forth the nature of the present invention, what is claimed is:

1. A method of making a fuel gas in a gasifier including a molten metal, a molten metal froth and an off-take section comprising,

   injecting from a center main injection lance a first solid carbonaceous fuel into the molten metal and a first material selected from a first hydrocarbon, carbon dioxide, oxygen, steam and combinations thereof into at least one of the molten metal, the molten metal froth and the off-take zone,

   injecting from a top perimeter lance injection system a second material selected from a second hydrocarbon, carbon dioxide, oxygen, steam and combinations thereof into at least one of the molten metal, the molten metal froth and the off-take zone,

   injecting from a side lance injection system a second solid carbonaceous fuel into the molten metal and a third material selected from a third hydrocarbon, carbon dioxide, oxygen, steam and combinations thereof into at least one of the molten metal and molten metal froth, and

   injecting from a bottom lance injection system a fourth hydrocarbon.

2. The method according to claim 1 further comprising creating a desired flow within the gasifier selected from a counter turbulent flow, a cyclonic flow and a combination thereof.

3. The method according to claim 2 wherein the desired flow is created within at least one of the molten metal, the molten metal froth and the gas off-take zone.
4. The method according to claim 2 wherein the desired flow is created from the injection of at least two of the first material, the second material, the third material and the fourth material into the gasifier.

5. The method according to claim 1 further comprising horizontal rotational stirring the molten metal by injecting a material selected from the second material, the third material, the fourth material and combinations thereof.

6. The method according to claim 1 further comprising adjusting a stand off distance between the molten metal and the center main injection lance in response to a feedback.

7. The method according to claim 1 further comprising adjusting a stand off distance between the molten metal and a top perimeter lance of the top perimeter lance injection system in response to a feedback.

8. The method according to claim 1 further comprising adjusting a stand off distance between the molten metal and a side injection lance of the side lance injection system in response to a feedback.

9. The method according to claim 1 wherein the first solid carbonaceous fuel is selected from municipal solid waste, waxes, medical waste, glycerins, household hazardous waste, contaminated carbon, spent tires, contaminated filters, biomass, petroleum coke, bio-solids, construction materials, coal, tars, asphalt, agricultural waste, industrial waste and combinations thereof.

10. The method according to claim 1 further comprising varying an injection velocity of one or more of the first solid carbonaceous fuel, the first material, the second material and the third material.
11. The method according to claim 1 further comprising controlling the size of the molten metal froth zone by injecting a material selected from the first material, the second material, the third material and a combination thereof into the off-take zone.

12. A method of making a fuel gas comprising,

   providing a center main injection lance and injecting from the center main injection lance a first material stream into a molten metal bath, a second material stream into a molten metal froth, and a third material stream into an off-take zone, and

   providing a plurality of top perimeter injection lances and injecting from at least one of the top perimeter lances a fourth material stream into the molten metal bath, a fifth material stream into the molten metal froth and a sixth material stream into the off-take zone.

13. The method according to claim 12 further comprising providing one or more side injection lances and injecting from at least one of the one or more side injection lances a seventh material stream into at least one of the molten metal bath and molten metal froth.

14. The method according to claim 13 further comprising providing one or more bottom injection lances and injecting from at least one of the one or more bottom injection lances an eighth material stream into the molten metal.

15. The method according to claim 12 further comprising varying a first stand off distance between the molten metal bath and the center main injection lance and varying a second stand off distance between the molten metal bath and at least one
top perimeter injection lance of the plurality of top perimeter injection lances in response to a feedback.

16. The method according to claim 12 further comprising decreasing a volume of the molten metal froth by injecting the third material stream and the sixth material stream.

17. The method according to claim 12 wherein each of the first material stream, the second material stream, the third material stream, the fourth material stream, the fifth material stream, and the sixth material stream is selected from a solid carbonaceous fuel, a liquid carbonaceous fuel, a gaseous carbonaceous fuel, oxygen, carbon dioxide, steam and combinations thereof.

18. The method according to claim 12 further comprising creating a flow pattern selected from a counter turbulent flow, a cyclonic flow and combinations thereof by injecting at least two of the second material stream, the third material stream, the fifth material stream, and the sixth material stream.

19. A method of making a fuel gas comprising,

introducing a plurality of material feed streams into a molten metal gasifier using a lance injection system, wherein the lance injection system selectively introduces each material feed stream of the plurality of material feed streams into one of a plurality of desired locations within the gasifier.

20. The method according to claim 19 wherein the plurality of desired locations within the gasifier include a molten metal bath, a molten metal froth and an off-take zone.
21. The method according to claim 19 further comprising varying a standoff distance between at least one of the plurality of lances and a molten metal bath surface in response to a feedback.

22. The method according to claim 19 further comprising creating a flow pattern selected from a counter turbulent flow pattern, a cyclonic flow pattern and combinations thereof within the gasifier by introducing the plurality of feed materials into the molten metal gasifier using the lance injection system.

23. The method according to claim 22 wherein the desired flow is created within a molten metal froth.

24. The method according to claim 19 further comprising decreasing a volume of a molten metal froth by introducing at least one of the material feeds of the plurality of feed materials into the molten metal gasifier using the lance injection system.

25. The method according to claim 24 wherein the at least one of the material feeds is introduced into an off-take zone of the gasifier.

26. The method according to claim 19 further comprising creating a desired flow direction and a desired flow velocity within the molten metal gasifier based upon feedback.

27. The method according to claim 19 further comprising creating and maintaining an exothermic reaction by introducing the plurality of material feed streams into the molten metal gasifier in response to a feedback.

28. The method according to claim 1 further comprising injecting carbon into the gasifier at a first rate and oxidizing the carbon in the gasifier to carbon
monoxide at a second rate wherein the first rate and the second rate are substantially the same.

29. The method according to claim 1 further comprising injecting carbon into the gasifier at a first rate and oxidizing the molten metal and the molten metal froth at a second rate wherein the first rate and the second rate are substantially the same.

30. The method according to claim 1 further comprising oxidizing the molten metal and the molten metal froth to metal oxide at a first rate and reducing the metal oxide with carbon at a second rate wherein the first rate and the second rate are substantially the same.

31. The method according to claim 19 further comprising injecting carbon in the plurality of material feed streams into the molten metal gasifier at a first rate and oxidizing carbon in the molten metal gasifier to carbon monoxide at a second rate wherein the first rate and the second rate are substantially the same.

32. The method according to claim 19 further comprising injecting carbon in the plurality of material feed streams into the molten metal gasifier at a first rate and oxidizing a molten metal in the molten metal gasifier at a second rate wherein the first rate and the second rate are substantially the same.

33. The method according to claim 19 further comprising oxidizing a molten metal in the molten metal gasifier to metal oxide at a first rate and reducing the metal oxide with carbon in the plurality of material feed streams at a second rate wherein the first rate and the second rate are substantially the same.