A system includes an integrated reactor-syngas cooler that may gasify a feedstock. The integrated reactor-syngas cooler includes a reaction zone that may receive a first syngas and the feedstock, and that may gasify the feedstock to generate a second syngas. The second syngas has a composition different from the first syngas. The system also includes one or more feed injectors disposed in the integrated reactor-syngas cooler and that may supply the feedstock to the reaction zone and a cooling zone disposed downstream of the reaction zone and including one or more cooling tubes. The cooling zone may receive and cool the second syngas.
FIG. 9

1. PROVIDE FEEDSTOCK TO GASIFIER
2. GASIFY FEEDSTOCK IN GASIFIER TO GENERATE FIRST SYNGAS
3. DIRECT FIRST SYNGAS TO SYNGAS COOLER REACTOR
4. PROVIDE SYNGAS COOLER REACTOR WITH ADDITIONAL FEEDSTOCK
5. GASIFY ADDITIONAL FEEDSTOCK IN SYNGAS COOLER REACTOR TO GENERATE SECOND SYNGAS
6. ADJUST AN AMOUNT OF GASIFICATION COMPONENTS SUPPLIED TO THE SYNGAS COOLER REACTOR TO ENRICH SECOND SYNGAS WITH CH₄ OR H₂
7. DIRECT SECOND SYNGAS TO COOLING REGION OF SYNGAS COOLER
8. COOL SECOND SYNGAS
SYSTEM AND METHOD FOR GASIFICATION

BACKGROUND

[0001] The subject matter disclosed herein relates to gasification systems and, more particularly, to an integrated reactor-syngas cooler that may be used with a gasifier to improve the efficiency of the gasification system and to adjust the composition of the final product gas.

[0002] Gasifiers convert carbonaceous materials into a gaseous mixture consisting primarily of carbon monoxide and hydrogen, referred to as synthesis gas or syngas. For example, a gasification system may include one or more gasifiers that react a feedstock at a high temperature with oxygen and water or steam to produce syngas. The syngas may be used for power generation, chemical production, or any other suitable application. Prior to use, the syngas may be cooled in a syngas cooler and treated in a gas treatment system.

BRIEF DESCRIPTION

[0003] Certain embodiments commensurate in scope with the originally claimed invention are summarized below. These embodiments are not intended to limit the scope of the claimed invention, but rather these embodiments are intended only to provide a brief summary of possible forms of the invention. Indeed, the invention may encompass a variety of forms that may be similar to or different from the embodiments set forth below.

[0004] In a first embodiment, a system includes an integrated reactor-syngas cooler that may gasify a feedstock. The integrated reactor-syngas cooler includes a reaction zone that may receive a first syngas and the feedstock, and that may gasify the feedstock to generate a second syngas. The second syngas has a composition different from the first syngas. The system also includes one or more feed injectors disposed in the integrated reactor-syngas cooler and that may supply the feedstock to the reaction zone and a cooling zone disposed downstream of the reaction zone and including one or more cooling tubes. The cooling zone may receive and cool the second syngas.

[0005] In a second embodiment, a method includes gasifying a first feedstock in a gasifier to generate a first syngas, directing the first syngas to an integrated reactor-syngas cooler fluidly coupled to the gasifier, and supplying a second feedstock to the integrated reactor-syngas cooler. The integrated reactor-syngas cooler includes a reaction zone that may gasify the second feedstock by reaction with the first syngas to generate a second syngas. The method also includes adjusting an amount of the second feedstock supplied to the reaction zone of the integrated reactor-syngas cooler to adjust a composition of the second syngas.

[0006] In a third embodiment, a system includes a controller including one or more tangible, non-transitory, machine-readable media collectively storing one or more sets of instructions and one or more processing devices that may execute the one or more sets of instructions to monitor or control operations of the system. The controller also includes one or more sets of instructions that may supply a first feedstock to a gasifier and a second feedstock to a reaction zone of an integrated reactor-syngas cooler disposed downstream of the gasifier. The gasifier is fluidly coupled to the reaction zone of the integrated reactor-syngas cooler and may gasify the first feedstock to generate a first syngas. The controller also includes one or more sets of instructions that are configured to gasify the second feedstock in the reaction zone of the integrated reactor-syngas cooler to generate a second syngas. The reaction zone of the integrated reactor-syngas cooler utilizes heat from the first syngas to gasify the second feedstock. The one or more sets of instructions may also adjust an amount of the second feedstock in the reaction zone of the integrated reactor-syngas cooler to enrich the second syngas with methane or hydrogen and adjust the temperature of the second syngas.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0008] FIG. 1 is a block diagram of an embodiment of a gasification system including a gasifier configured to generate a first syngas and an integrated reactor-syngas cooler configured to generate a second syngas;

[0009] FIG. 2 is a cross-sectional view of an embodiment of the integrated reactor-syngas cooler that may be used with the gasification system of FIG. 1;

[0010] FIG. 3 is an embodiment of the integrated reactor-syngas cooler of FIG. 2 having feed injector nozzles axially distributed in a syngas cooler upper region;

[0011] FIG. 4 is an embodiment of the integrated reactor-syngas cooler of FIG. 2 having feed injector nozzles radially distributed on the syngas cooler upper region;

[0012] FIG. 5 is an embodiment of the integrated reactor-syngas cooler of FIG. 2 having helical cooling tubes;

[0013] FIG. 6 is a cross-sectional view of an embodiment of the integrated reactor-syngas cooler of FIG. 2 in which the second syngas is quenched prior to exiting the integrated reactor-syngas cooler;

[0014] FIG. 7 is a cross-sectional view of an embodiment of the integrated reactor-syngas cooler of FIG. 2 in which the second syngas is partially quenched prior to exiting the integrated reactor-syngas cooler;

[0015] FIG. 8 is a cross-sectional view of an embodiment of a portion of the gasification system of FIG. 1 having a particle removal step inserted between the gasifier and the integrated reactor-syngas cooler; and

[0016] FIG. 9 is a flow chart that shows a method for generating a syngas enriched with methane (CH₄) or hydrogen (H₂) in accordance with certain embodiments.

DETAILED DESCRIPTION

[0017] One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.
[0018] When introducing elements of various embodiments of the present invention, the articles “a,” “an,” “the,” and “said” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0019] As discussed in detail below, the disclosed embodiments include a multi-stage (e.g., two-stage) gasification system including a gasifier (e.g., a reactor) and an integrated reactor-syngas cooler reactor (e.g., a reactor) designed to adjust a composition of a syngas generated in the gasifier. Generally, during gasification, a feedstock (e.g., fuel) undergoes partial oxidation in the gasifier to produce a syngas. The resultant syngas flows into the integrated reactor-syngas cooler reactor and mixes with additional feedstock supplied to the integrated reactor-syngas cooler reactor by one or more feed injectors. The additional feedstock absorbs heat from the syngas, simultaneously cooling and increasing the methane content of the syngas, the latter of which is favored by the lower temperatures. Accordingly, the gasification system may facilitate the production of synthetic natural gas (SNG). In addition, by controlling an amount of the additional feedstock and water, steam or other chemical species supplied to the integrated reactor-syngas cooler reactor, a composition of the syngas may be adjusted. For example, an amount of methane (CH₄) or a ratio of carbon monoxide (CO) and hydrogen (H₂) in the syngas may be adjusted for use in power, coal-to-liquids (CTL), and chemical plant applications and to increase gasification efficiency. Accordingly, provided herein is an integrated reactor-syngas cooler reactor configured to adjust the composition of a syngas generated in an upstream gasifier to produce a CH₄ (e.g., synthetic natural gas) or H₂ enriched syngas.

[0020] FIG. 1 illustrates an embodiment of a gasification system 10 including a gasifier 12 that generates a first syngas 14 and an integrated reactor-syngas cooler 16 (e.g., a syngas cooler with a reactor or reaction zone and a cooler or cooling zone in a single housing) including an integrated reactor-syngas cooler reactor 18 configured to generate a second syngas 20 (e.g., CO, H₂, methane, synthetic natural gas (SNG)) for use in one or more downstream applications, and an integrated reactor-syngas cooler cooling zone 19 configured to absorb heat from syngas 20, such as in the form of steam (e.g., steam 72). For example, the second syngas 20 and at least a portion of the steam 72 may be used to operate a power generation system 26, a chemical production system 28, a coal-to-liquids (CTL) system 30, a methanol-to-olefin chemical system (MTO) 34, a synthetic natural gas chemical plant (SNG) 38, and/or other suitable systems or applications.

[0021] As illustrated, the gasifier 12 receives reactants from a feed system 40. The feed system 40 supplies a feedstock 42 and a gasifying agent 44 (e.g., air, oxygen, oxidant, etc.) to the gasifier 12. The feedstock 42 is utilized as a source of energy for the gasification system 10. The feedstock 42 may include coal, petroleum coke, biomass, wood-based materials, agricultural wastes, tars, asphalt, heavy residues from a refinery, or other carbon containing items. Prior to gasification, the feedstock 42 may be resized or reshaped in the feed system 40 by chopping, milling, shredding, pulverizing, briquetting, or pelletizing the feedstock 42. Additionally, water, or other suitable liquids may be added to the feedstock 42 to create slurry-type feedstock. In other embodiments, no liquid is added to the feedstock 42, or feedstock 42 may be at least partially dried, thus yielding a dry-type feedstock that may be combined with a pressurization and/or carrier gas.

[0022] As will be described in more detail below, the gasifier 12 includes a reactor or a reaction chamber disposed in a gasification vessel to enable gasification of the feedstock 42 to produce the first syngas 14. The gasifier 12 may convert the feedstock 42 into the syngas 14, e.g., a combination of carbon monoxide (CO) and hydrogen (H₂). This conversion may be accomplished by subjecting the feedstock 42 to controlled amounts of gasifying agent 44 (e.g., pure oxygen, air, or a mixture thereof) and steam 48 or moderator 52 (e.g., steam, water or carbon dioxide) at elevated pressures, e.g., from approximately 20 bar to 85 bar, and temperatures, e.g., approximately 1100 degrees Celsius (C) to 1600 degrees C, depending on the type of gasifier 12 utilized. The gasifier 12 may be an entrained-flow gasifier, such as an updraft or downdraft entrained flow gasifier. Alternatively, in some embodiments, gasifier 12 may be a fluidized-bed gasifier, such as a bubbling fluidized-bed gasifier or a circulating fluidized-bed gasifier. Also, although feedstock 42 and moderator 52 are depicted separately in FIG. 1, in many cases, the slurry liquid (e.g., the slurry-type feedstock) and/or the pressurization and/or carrier gas (e.g., in the dry-type feedstock) may be one and the same as moderator 52.

[0023] The actual gasification process reactions may be viewed as occurring in different steps. For example, during the gasification process, the feedstock 42 may first undergo a pyrolysis process, whereby the feedstock 42 is heated, yielding a combination of volatiles and char. The volatiles generated during the pyrolysis process, also known as devolatilization, may be partially combusted by reaction with gasifying agent 44. The volatiles may react with the gasifying agent 44 to form carbon dioxide (CO₂) and CO in partial combustion reactions, which provide heat for the subsequent gasification reactions. Char generated during the devolatilization may react with the CO₂ and steam to produce CO and H₂. In essence, the gasifier 12 utilizes steam 48 and the gasifying agent 44 to partially oxidize some of the feedstock 42 to produce CO and release energy, which drives additional reactions, including converting further feedstock 42 to H₂ and additional CO₂ via a reaction known as the water-gas-shift reaction.

[0024] In this way, the gasifier 12 manufactures a resultant gas (e.g., the syngas 14). This resultant gas may include as much as 82% of CO and H₂ in equal proportions, as well as CO₂, H₂O, CH₄, HCl, HF, COS, NH₃, HCN, and H₂S. This resultant gas may be termed untreated syngas, because it includes undesirable byproducts, for example, H₂S and COS. The gasifier 12 may also generate waste that, depending on the type of gasifier and the feedstock used, may be comprised of a slag/particulate mixture 50. As should be noted, the slag/particulate mixture 50 may include slag, fine ash, and char, at least a portion of which may be a wet ash material. This slag/particulate mixture 50 may be at least partially cooled and removed from the syngas 14 during cooling of the untreated syngas in the integrated reactor-syngas cooler 16 and/or downstream. Further, it is during this cooling and subsequent process steps prior to discharge from system 10 that most of any wet ash material is likely to be converted to dry ash material.

[0025] The integrated reactor-syngas cooler 16 may include features that may facilitate the augmentation and/or further reduction (e.g., methanation) of the syngas 14. For example, the integrated reactor-syngas cooler 16 may be con-
figured to receive additional feedstock (e.g., feedstock 42). The additional feedstock may absorb heat from the first syngas 14 in the integrated reactor-syngas cooler reactor 18 and undergo a methanation reaction, thereby generating methane (e.g., the second syngas 20). In certain embodiments, the integrated reactor-syngas cooler reactor 18 may be supplied with a moderator 52 (e.g., steam) to facilitate the further conversion of feedstock, and production of methane (e.g., the second syngas 20), or may also receive in addition to or alternatively a reactive gas, such as CO₂, that may react with the first syngas 14 and second feedstock 42 to increase the yield of the second syngas 20. Additionally, the integrated reactor-syngas cooler 16 may include features that may facilitate cooling of the second syngas 20 as it flows through the integrated reactor-syngas cooler 16. For example, the integrated reactor-syngas cooler 16 may include cooling tubes (e.g., a heat exchanger) in a downstream cooling portion of the integrated reactor-syngas cooler 16 (e.g., cooling zone 19) that may cool the second syngas 20 via indirect heat transfer with a coolant flowing through the cooling tubes. Moreover, the integrated reactor-syngas cooler 16 may be useful for separating particulates, e.g., the slag/particulate mixture 50 from the gasifier, as well as any additional particulates produced that add to the slag/particulate mixture 50 as a result of the reaction of the additional feedstock introduced into integrated reactor-syngas cooler reactor 18 that may be mixed with the first and second syngas 14 and 20, respectively, prior to transmission of the second syngas 20 to the corresponding system (e.g., the power generation system 26, chemical production system 28, CTL system 30, MTO system 34, and/or SNG plant 38). As should be noted, the second syngas 20 may undergo additional processing (e.g., scrubbing, purification, etc.) downstream of the integrated reactor-syngas cooler 16 before use.

[0026] The gasification system 10 may also include a controller 60 (e.g., an electronic and/or processor-based controller) to govern operation of the gasification system 10. The controller 60 may independently control operation of the gasification system 10 by electrically communicating with sensors, control valves (e.g., valves 64, 66, 68, and 70), and pumps, or other flow adjusting features throughout the gasification system 10. The controller 60 may include a distributed control system (DCS) or any computer-based workstation that is fully or partially automated. For example, the controller 60 can be any device employing a general purpose or an application-specific processor, both of which may generally include memory circuitry for storing instructions such as gasification parameters (e.g., the gasification conditions of the feedstock 42). The processor may include one or more processing devices, and the memory circuitry may include one or more tangible, non-transitory, machine-readable media collectively storing instructions executable by the processor to perform the acts of FIG. 9, as discussed below, and control actions described herein.

[0027] In one embodiment, during operation of the gasification system 10, the controller 60 may operate flow control devices (e.g., valves, pumps, etc.) to control amounts and/or flows between the different system components. For example, the controller 60 may control valves 66 and 68 to adjust amounts of feedstock 42 supplied to the gasifier 12 and the integrated reactor-syngas cooler reactor 18, respectively. Similarly, the controller 60 may control the valves 64 and 70 to adjust amounts of the gasifying agent 44 to gasifier 12 and the moderator 52 to integrated reactor-syngas cooler reactor 18, respectively. In this way, gasification reactions (e.g., water gas, water-gas-shift, and methanation reactions) within the gasifier 12 and the integrated reactor-syngas cooler reactor 18 may be controlled by the controller 60. Accordingly, the composition of the first syngas 14, generated in the gasifier 12, and the second syngas 20, generated in the integrated reactor-syngas cooler reactor 18, may be adjusted, as described in further detail below. It should be noted that there may be additional valves throughout the gasification system 10 used to adjust different amounts and/or flows between the system components. For example, valves similar to valve 70 may be used to control the flow of steam 48 and moderator 52 to gasifier 12. Furthermore, other devices may be used for controlling flow rates of certain streams, including positive displacement pumps and other such metering devices without departing from the scope of the invention.

[0028] During startup of the gasification system 10, the controller 60 may execute a startup control module to control a flow of the gasifying agent 44, the feedstock 42, the moderator 52, and, when available, steam 48 supplied to the gasifier 12. In addition, during steady-state operation of the gasification system 10, the controller 60 may execute a steady-state control module to control a flow of the feedstock 42 and the moderator 52 to the integrated reactor-syngas cooler reactor 18, and flows of steam 48 and steam 72 generated in the integrated reactor-syngas cooler 16 to gasifier 12, integrated reactor-syngas cooler reactor 18, and/or other associated systems (e.g., systems 26, 28, 30, 34, and 36), processes and equipment. The controller 60 may use various startup and steady-state control modules to control operations differently during startup and steady-state. For example, during startup, the controller 60 may flow a first amount of the feedstock 42, the gasifying agent 44, and/or the moderator 52 into the gasifier 12 such that the first syngas 14 has a CO/H₂ ratio that facilitates generation of a desired composition of the second syngas 20 (e.g., H₂ or CH₄ enriched). During steady-state operation, the controller 60 may gradually adjust a second amount of the feedstock 42, the gasifying agent 44, the steam 48, and/or the moderator 52 flowing through the gasifier 12 and/or the integrated reactor-syngas cooler reactor 18 to maintain or adjust the composition of the second syngas 20. For example, during startup of the gasification system 10, increased steam generation may be desired. As such, the controller 60 may send a higher flow of the feedstock 42 to the gasifier 12 and a reduced flow of the feedstock 42 to the integrated reactor-syngas cooler 16 by controlling the valves 66 and 68. Controller 60 may then gradually decrease a flow of the feedstock 42 to the gasifier 12 and gradually increase a flow of feedstock 42 to the integrated reactor-syngas cooler 16 to approach steady-state conditions, while simultaneously adjusting the flows of gasifying agent 44, steam 48 and moderator 52. In this way, the flow of the feedstock 42 and other feeds may be gradually balanced, or otherwise adjusted, between the gasifier 12 and the integrated reactor-syngas cooler 16 over time to achieve a desired set of operating conditions. In addition, during steady-state operation, the controller 60 may also optimize a composition of the syngas (e.g., the first syngas 14 and/or the second syngas 20) to a rate of steam generation according to an end-use (e.g., the power generation, chemical production, coal-to-liquid process, and/or synthetic natural gas) of the second syngas 20 by controlling the valves 66 and 68 and setting the flow of the feedstock 42 at a desired rate. In certain embodiments, the controller 60 may control flow devices that may be part of a weighing
mechanism that measures the amount of the feedstock 42, before it enters the gasifier 12 and/or the integrated reactor-syngas cooler reactor 18. In certain embodiments, the controller 60 may use information provided via input signals to execute instructions or code contained on a machine-readable or computer-readable storage medium and generate one or more output signals 74 to the various flow control devices (e.g., valves 64, 66, 68, and 70) to control a flow of fluids within the gasification system 10, for example, the gasifying agent 44, the feedstock 42, and the moderator 52.

As should be appreciated, the controller 60 may control the flow of the gasification components (e.g., the feedstock 42, the gasifying agent 44, steam 48, and the moderator 52) via any other suitable methods. For example, in embodiments where the feedstock 42 is a slurry feed, a metering pump may be used. The metering pump may be operated on a speed or a flow control instead of using a flow control valve to regulate the flow of the slurry feed.

As discussed above, the first syngas 14 flows through the integrated reactor-syngas cooler 16 (e.g., a cylindrical vessel having a reactor zone (e.g., the integrated reactor-syngas cooler reactor 18) and a cooling zone 19). The integrated reactor-syngas cooler 16 may be configured to adjust the composition of the first syngas 14 to generate the second syngas 20. FIG. 2 is a cross-sectional view of an embodiment of the integrated reactor-syngas cooler 16 for use with the gasification system 10 of FIG. 1. Various aspects of the integrated reactor-syngas cooler 16 may be described with reference to an axial direction or axis 100, a radial direction or axis 102, and a circumferential direction or axis 104. For example, the axis 100 corresponds to a longitudinal centerline 106 or lengthwise direction, the axis 102 corresponds to a crosswise or radial direction relative to the longitudinal centerline 106, and the axis 104 corresponds to the circumferential direction about the longitudinal centerline 100. The integrated reactor-syngas cooler 16 may include a vessel 110 (e.g., a cylindrical vessel) that may act as an enclosure that functions as a housing or outer casing for the integrated reactor-syngas cooler 16. The vessel 110 encloses both the integrated reactor-syngas cooler reactor 18 (e.g., the reaction zone) in an upper cylindrical shell portion 114 and a cooling zone 19 (e.g., cooling region) in a lower cylindrical shell portion 118 of the integrated reactor-syngas cooler 16.

The cooling zone 19 may include cooling tubes 120 that facilitate cooling of the syngas (e.g., the second syngas 20) as it flows through the integrated reactor-syngas cooler 16 via syngas cooling zone opening 124, as indicated by arrow 126. The cooling tubing 120 may include a plurality of conduits at one or more radii parallel to axial axis 100 of the integrated reactor-syngas cooler 16, and may also include a plurality of conduits that run at one or more angles along radial axis 102, as well as along one or more radii that run along circumferential axis 104. A coolant 128, such as water or another liquid, may flow through the cooling tubing 120. Thus, the cooling tubing 120 may act as a heat exchanger within the integrated reactor-syngas cooler 16, and may circulate the coolant 128 for removal of heat from the second syngas 20 and associated slag/particulate mixture 50, as discussed in further detail below.

In some embodiments, outer diameters of a number of the cooling tubing 120 forming the plurality of conduits may be joined together to form a closed surface. Such joining may be by a number of methods, including but not limited to direct tube to tube welding, or welding using an intermediate plate or web material between adjacent tubes. In certain embodiments, the closed surfaces may be used to channel the syngas 20 and slag, fine ash and char 50 through cooling zone 19, enhancing the effectiveness of heat exchange within cooling zone 19. In still other embodiments, such closed surfaces may be used as a protective barrier to prevent syngas 20 and the slag/particulate mixture 50 from directly contacting portions of the vessel 110, thereby protecting the vessel 110 from exposure to excessive temperatures and corrosion. Other protective barriers may be used in cooling zone 19 as described in further detail below.

As discussed above, the integrated reactor-syngas cooler 16 is configured to receive the first syngas 14 and additional feedstock (e.g., the feedstock 42) to adjust the composition of the first syngas 14. As should be noted, the additional feedstock supplied to the integrated reactor-syngas cooler reactor 18 may be the same or different from the feedstock 42 supplied to the gasifier 12. In addition, an amount and/or flow rate of the additional feedstock flowing into the integrated reactor-syngas cooler reactor 18 may be the same or different from an amount and/or flow of the feedstock 42 flowing into the gasifier 12. The vessel 110 also includes a reaction chamber opening 130 (e.g., central axial opening) and one or more feed injector openings 132 positioned circumferentially 104 around the upper cylindrical shell portion 114 that provide a passage for the first syngas 14 and the additional feedstock (e.g., the feedstock 42), respectively, and circulate the first syngas 14 and the additional feedstock to an axial opening 18 of the integrated reactor-syngas cooler 16. For example, the reaction chamber opening 130 may receive the first syngas 14, as indicated by arrow 14, from the gasifier 12. Similarly, one or more feed injectors 140 may supply the additional feedstock to the integrated reactor-syngas cooler reactor 18 through the one or more feed injector openings 132, as indicated by arrows 142. The additional feedstock 142 utilizes heat from the first syngas 14 and undergoes pyrolysis to generate char (C), CO, CO2, H2, H2O and CH4. As such, the additional syngas 142 may quench the first syngas 14, thereby decreasing a temperature of the first syngas 14 and operational temperatures of the integrated reactor-syngas cooler reactor 18. As discussed in further detail below, this temperature decrease may be favorable for CH4 production. As should be noted, the one or more feed injectors may also supply other components to the integrated reactor-syngas cooler 16. For example, in certain embodiments, the one or more feed injectors 140 may supply an atomizing medium such as nitrogen, steam, recycle syngas, CO2, or combinations thereof, depending on the downstream application of the second syngas 20. As such, the one or more feed injectors 140 may include a 2 or 3-stream nozzle arrangement.

During gasification of the additional feedstock 142, steam (e.g., the moderator 52) may be introduced into the integrated reactor-syngas cooler reactor 18. The steam may react with the char generated during pyrolysis of the additional feedstock 142 to produce H2 and CO via a process known as the water gas reaction. The additional feedstock 142 utilizes heat from the first syngas 14 during pyrolysis. The H2 generated during pyrolysis of the additional feedstock 142 and the H2 present in the first syngas 14 may also react with the char to generate methane via the methanation reaction. In addition, the steam may also react with the CO generated during the gasification of the additional feedstock 142 to generate CO2 and H2 (e.g., the water-gas shift reaction). Simi-
larly, the H₂ generated via the water-gas-shift reaction may react with the char to generate CH₄. Therefore, the second syngas 20 may be enriched with CH₄.

[0035] As discussed above, the additional feedstock 142 quenches the first syngas 14, thereby reducing the temperature of the first syngas 14 and the overall operational temperature of the integrated reactor-syngas cooler reactor 18. Accordingly, by controlling an amount of the additional feedstock 142 supplied to the integrated reactor-syngas cooler reactor 18, an amount of CH₄ and/or H₂ present in the second syngas 20 may be adjusted. In certain embodiments, the amount of the additional feedstock 142 (e.g., between approximately 15% to 20% of an amount of the feedstock 42 supplied to the gasifier 12) may decrease the temperature of the first syngas 14 to below approximately 1100 degrees C. As such, the operational temperature of the integrated reactor-syngas cooler reactor 18 may be more favorable for the methanation reaction and the second syngas 20 may be enriched with CH₄. In other embodiments, the amount of the additional feedstock 142 (e.g., between approximately 5% to 10% of an amount of the feedstock 42 supplied to the gasifier 12) may decrease the temperature of the first syngas 14 to between approximately 1400° C. to approximately 1100° C. Therefore, the operational temperature of the integrated reactor-syngas cooler reactor 18 may be more favorable for the water-gas shift reaction. Accordingly, the second syngas 20 may be enriched with H₂. In this way, the additional feedstock 142 may be used to adjust the CO/H₂ ratio of the second syngas 20.

[0036] Varying the residence time or size of the integrated reactor-syngas cooler reactor 18 may also impact the composition of the second syngas 20. For example, with a high volatile carbonaceous feedstock, the additional feedstock 142 may generate an H₂ enriched syngas (e.g., the second syngas 20) in a smaller integrated reactor-syngas cooler reactor (e.g., integrated reactor-syngas cooler reactor 18) occupying a volume of approximately 10% to 20% of the integrated reactor-syngas cooler reactor 16 compared to a larger integrated reactor-syngas cooler reactor (e.g., an integrated reactor-syngas cooler reactor 18) occupying a volume of approximately more than 20% of the integrated reactor-syngas cooler 16).

[0037] Furthermore, varying the type of feed used for the additional feedstock 142 may also alter the overall composition of the second syngas 20 with respect to the amounts of methane and/or CO/H₂ ratio. For example, in certain embodiments, the additional feedstock 142 may be a high volatile carbonaceous feedstock with a high hydrogen to carbon ratio. Therefore, CH₄ formation within the integrated reactor-syngas cooler reactor 18 may be favored by devolatilization followed by char reactions with the first syngas 14 to further enhance formation of CH₄. In contrast, CH₄ formation will be reduced in the case where the additional feedstock 142 is a low volatile carbonaceous feedstock with a low hydrogen to carbon ratio, necessitating longer residence times. Accordingly, the integrated reactor-syngas cooler reactor 18 used with a high volatile carbonaceous feedstock with a high hydrogen to carbon ratio may occupy a smaller volume within the integrated reactor-syngas cooler reactor 16 compared to the case where the additional feedstock 142 is a low volatile carbonaceous feedstock with a low hydrogen to carbon ratio, such as recycle soot or coke.

[0038] As should be appreciated, the feedstock 42 and the additional feedstock 142 may be the same or different depending on the desired composition of the second syngas 20. For example, in certain embodiments, the feedstock 42 may be a low volatile carbonaceous feedstock and may maximize H₂ and CO generation in the gasifier 12 and the additional feedstock 142 may be a high volatile carbonaceous feedstock to maximize CH₄ output of the integrated reactor-syngas cooler reactor 18. As such, the second syngas 20 may be H₂ or CH₄-enriched.

[0039] The integrated reactor-syngas cooler reactor 18 may include certain features that facilitate formation of methane. For example, while methane formation may be favored under the operational conditions of the integrated reactor-syngas cooler reactor 18 (e.g., at temperatures below approximately 1100° C.), the kinetics of the methanation reaction are generally slow. As such, it may be desirable to increase a residence time of the gasification components (e.g., the first syngas 14, the moderator 52, and the additional feedstock 142) in the integrated reactor-syngas cooler reactor 18. In certain embodiments, a gap 150 between the reaction chamber 130 opening and the syngas cooler opening 124 may be between approximately 20% to approximately 50% of a length 154 of the integrated reactor-syngas cooler 16. As such, the desired residence time for the gasification components within the integrated reactor-syngas cooler reactor 18 may be achieved, thereby generating the second syngas 20 enriched with CH₄. In other embodiments, the gap 150 may be approximately between 5% to approximately 15% of the length 154. This configuration may be more favorable for generating an H₂ enriched syngas (e.g., the second syngas 20).

[0040] In addition to increasing the residence time of the gasification components (e.g., the first syngas 14, the moderator 52, and the additional feedstock 142), the one or more feed injectors 140 may be positioned such that the mixing of the additional feedstock 142 with the first syngas 14 and the temperature distribution within the integrated reactor-syngas cooler reactor 18 may be controlled. FIGS. 3 and 4 illustrate feed injector configurations that may be suitable for supplying the additional feedstock 142 and/or the moderator 52 (e.g., steam) to the integrated reactor-syngas cooler reactor 18. FIG. 3 is a perspective view of an embodiment of the one or more feed injectors 140 circumferentially (e.g., axis 104) staggered around the upper cylindrical shell portion 114 (e.g., dome portion) such that the one or more feed injectors 140 may direct the additional feedstock 142 and/or the moderator 52 both axially (e.g., axis 100) and inwardly (e.g., center axis 106), so that the additional feedstock 142 and/or the moderator 52 (e.g., steam) from each feed injector 140 may converge towards the centerline axis 106. The one or more feed injectors 140 may output the additional feedstock 142 and/or the moderator 52 at an acute angle 160 (e.g., less than approximately 90 degrees) relative to the centerline axis 106. For example, the acute angle 160 may be between approximately 0 to 89, 10 to 80, 20 to 70, 30 to 60, 40 to 50 degrees, or any other suitable angle to direct the additional feedstock 142 and/or the moderator 52 towards the cooling tubes 120. In certain embodiments, the one or more feed injectors 140 may be arranged in a cluster at the upper cylindrical shell portion 114 (e.g., dome portion). The acute angle 160, with respect to the centerline axis 106, may allow the one or more feed injectors 140 to direct a flow of the additional feedstock 142 in a direction substantially parallel to a flow of the first syngas 14 flowing from the gasifier 14 and into the integrated reactor-syngas cooler reactor 18. As such, an axial momentum of the first syngas 14 may increase and temperatures within the
integrated reactor-syngas cooler reactor 18 may decrease over a relatively longer axial distance. The aerodynamics within the integrated reactor-syngas cooler reactor 18 may allow the second syngas 20 to exchange more heat with the cooling tubes 120 via forced convection, and thereby generate CH₄ along the direction of flow. This may also facilitate formation of steam (e.g., the steam 198) within the cooling tubes 120 due to cooling of the second syngas 20 along a longer axial distance.

[0041] FIG. 4 is a perspective view of an embodiment of the integrated reactor-syngas cooler 16 having the one or more feed injectors 140 oriented radially (e.g., radial axis 102) towards the centerline axis 106. Similar to the embodiment illustrated in FIG. 3, the gasification components (e.g., the additional feedstock 142 and/or the moderator 52) from each feed injector 140 converge at the centerline axis 106. As illustrated in FIG. 4, the one or more feed injectors 140 are positioned at different elevations (e.g., axial positions) along the integrated reactor-syngas cooler reactor 18. For example, a first portion of the one or more feed injectors 140 may be positioned at a first elevation that directs the output of gasification components at an acute angle 160 relative to an upstream direction along the centerline axis 106 and a second portion of the one or more feed injectors 140 may be positioned at a second elevation that directs the output of gasification components at an obtuse angle 162 (e.g., greater than approximately 90 degrees) relative to the upstream direction along the centerline axis 106. For example, the obtuse angle 162 may be between approximately 90° to 179°, 100° to 170°, 120° to 160°, 130° to 150°, or any other suitable angle to direct the additional feedstock 142 and/or the moderator 52 towards the centerline axis 106. This configuration may result in a uniform temperature distribution within the integrated reactor-syngas cooler reactor 18 and facilitate quenching of the first syngas 14 and promotion of reduction reactions (e.g., methanation). The temperature and momentum of the second syngas 20 may decrease within the integrated reactor-syngas cooler reactor 18 and heat transfer within the cooling zone 19 may resemble natural convection cooling rather than a forced convection cooling and a length of the cooling tubes 120 may be decreased. As such, the second syngas 20 may be enriched with methane while steam (e.g., the steam 190) generated within the cooling tubes 120 during cooling of the second syngas 20 may be decreased. In other embodiments, the one or more feed injectors 140 may create a swirling flow. For example, the one or more feed injectors 140 may output the additional feedstock 142 and/or the moderator 52 with circumferential clockwise or counterclockwise swirl (e.g., axis 104 about the axis 106). The circumferential swirling flow may facilitate uniform distribution of the gasification components, thereby improving gasification dynamics within the integrated reactor-syngas cooler reactor 18 and facilitating formation of methane. As should be noted, the one or more feed injectors 140 may operate independently from each other. Accordingly, the one or more feed injectors 140 may output the gasification components in a clockwise or counterclockwise direction and other feed injector 140 may output the gasification components in an opposite direction. Feed injectors configured to circumferentially swirl the additional feedstock 142 may allow the temperature of the second syngas 20 to decrease within a shorter distance along the centerline axis 106, compared to non-swirling feed injectors, and thereby a length of the cooling tubes 120 may be decreased.

[0042] Returning to FIG. 2, as discussed above, the integrated reactor-syngas cooler reactor 18 receives the first syngas 14, at a high temperature and high pressure, and the additional feedstock 142 to generate a syngas enriched with CH₄ or H₂ (e.g., the second syngas 20). Accordingly, a temperature range within the integrated reactor-syngas cooler reactor 18 may be between approximately 500 to 1500 degrees C. Therefore, to help protect the integrated reactor-syngas cooler 16 from the high temperature and high pressure in the integrated reactor-syngas cooler reactor 18, at least a portion of the upper cylindrical shell portion 114 may include a protective barrier 170 to help mitigate any potential undesirable effects that may be caused by the high temperature and high pressure within the integrated reactor-syngas cooler reactor 18. The protective barrier 170 may define the integrated reactor-syngas cooler reactor 18 and may act as a physical barrier, a thermal barrier, a chemical barrier, or any combination thereof. For example, the protective barrier 170 may be used to block overheating or provide corrosion protection to the vessel 110. The protective barrier 170 may include materials such as, but not limited to, refractory material, refractory metals, non-metallic materials, clays, ceramics, cements, and oxides of chromium, aluminum, silicon, magnesium, and calcium. In addition, the materials used for the protective barrier 170 may include bricks, castable, coatings, or combinations thereof. Furthermore, in certain embodiments, the protective barrier 170 may include a cooling wall, such as a cooling wall including multiple cooling tubes 120 that are cooled by coolant 128. In some embodiments, the protective barrier 170 may be part of a continuous structure protecting at least portions of both the reaction zone (e.g., the integrated reactor-syngas cooler reactor 18) and the cooling zone 19 of integrated reactor-syngas cooler 16. Furthermore, the protective barrier 170 may even incorporate a surface wetting film or transpiration cooling for additional protection.

[0043] Following gasification of the additional feedstock 142, the second syngas 20 is directed towards the cooling zone 19, as indicated by arrow 126. As discussed above, the coolant 128 (e.g., water) is supplied to the cooling tubes 120 to facilitate cooling of the second syngas 20. Accordingly, the integrated reactor-syngas cooler 16 may include a coolant inlet 174 and a coolant outlet 176 to facilitate circulation of the coolant through the cooling tubes 120. Therefore, the integrated reactor-syngas cooler 16 may act as a heat exchanger within the integrated reactor-syngas cooler 16, thereby cooling the second syngas 20 and facilitating separation of the slag/particulate mixture 50 from the second syngas 20. For example, during cooling, particulates (e.g., slag/particulate mixture 50) may separate from the second syngas 20, as indicated by arrow 178, and pass into a sump 180, which is located below the cooling tubes 120, through a sump opening 182. In certain embodiments, the sump 180 may be filled with a liquid 184 (e.g., water) or one or more chemicals (e.g., solvent) to facilitate cooling of the particulates (e.g., slag/particulate mixture 50) and for easier removal through a solids outlet 186. The cooled second syngas 20 is directed out of the integrated reactor-syngas cooler 16 via syngas outlet 190 for further processing (e.g., purification) and use in a power, chemical, or SNGL plant, as discussed above with reference to FIG. 1.

[0044] In certain embodiments, the cooling tubes 120 may be aligned with the centerline axis 106. In other embodiments, the cooling tubes 120 may be slanted (e.g., angled or
off-axis) from the centerline axis 106. That is, the cooling tubes 120 may be slanted by approximately 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 degrees or more from the centerline axis 106. The cooling tubes 120 may have a cage, a platen, a combination thereof, or any other suitable arrangement that facilitates heat transfer between the coolant 128 and the second syngas 20. For example, in one embodiment, the cooling tubes 120 may be arranged in annular rows (e.g., axis 100 and the centerline 106) within the integrated reactor-syngas cooler 16. The cooling tubes 120 may be spaced apart (e.g., not touching) or up against (e.g., touching) adjacent cooling tube 120 such that the annular rows of cooling tubes 120 form a cage-like structure within the integrated reactor-syngas cooler 16. In another embodiment, the cooling tubes 120 are arranged in radial rows (e.g., axial axis 102), where separate pairs of lower and upper radial rows are joined together with a plurality of axial tubes thereby forming platens. Similar to the annular row configuration, the cooling tubes 120 may be spaced apart or up against an adjacent cooling tube 120 within the same radial row. As should be noted, in other embodiments, the integrated reactor-syngas cooler 16 may have both cage and platen cooling tube arrangements. In other embodiments, the cooling tubes 120 may have a spiral (e.g., helical) arrangement. For example, FIG. 8 illustrates helical cooling tubes 196 in the cooling zone 19 (e.g., the lower cylindrical shell portion 118). In certain embodiments, the integrated reactor-syngas cooler 16 may have at least one or more helical, cage-like, or platen cooling tube configurations. Furthermore, the integrated reactor-syngas cooler 16 may be configured with any combination of the aforesaid cooling tube arrangements to facilitate cooling of the syngas.

During cooling of the second syngas 20 within the cooling zone 19, the heat from the second syngas 20 may cause the coolant passing through the cooling tubes 120 to vaporize, thereby producing steam 198, such as high-pressure steam (e.g., steam 48 and/or the moderator 52). The steam 198 produced in the integrated reactor-syngas cooler 16 may be used as a source of heat elsewhere in the gasification system 10 (e.g., an integrated gasification combined cycle IGCC) and/or chemical plant (e.g., MTO and/or SNG), as described above with reference to FIG. 1. For example, the steam 198 may be used as an input to a heat recovery steam generator (HRSG), a gas purifier system, a polygen system, a carbon capture system, a methanation system, a vapor absorption system, a process heat exchanger, a reactor, an attenuator, or any combination thereof. In certain embodiments, the steam 198 may be circulated to the integrated reactor-syngas cooler 18 (e.g., as the moderator 52) to drive gasification of the additional feedstock 142 and generate CH4. Accordingly, the integrated reactor-syngas cooler 16 advantageously generates and cools the second syngas 20 and produces large quantities of high-pressure steam (e.g., the steam 198), which may have numerous applications, including for power generation. In addition to cooling, the integrated reactor-syngas cooler 16 may also be configured to condition the second syngas 20. For example, as discussed above, cooling of the second syngas 20 may cause separation of the particulates (e.g., slag/particulate mixture 50) from the second syngas 20, causing at least a portion of the particulates to fall into the sump 180, as indicated by arrow 178.

FIG. 6 depicts a specific embodiment of the integrated reactor-syngas cooler 16 of FIG. 2 that provides for the further cooling of the second syngas 20 and the slag/particulate mixture 50, as well as at least partial separation of the slag/particulate mixture 50 from the syngas 20 in the downstream portion of cooling zone 19. In this embodiment, the integrated reactor-syngas cooler 16 includes a quench zone 200 located downstream of an indirect heat exchange portion 202 of cooling zone 19, wherein the second syngas 20 and slag/particulate mixture 50 are contacted directly with the liquid 184 (e.g., water) in the sump area 180. Further cooling of the second syngas 20 and the slag/particulate mixture 50 so the second syngas 20 may become saturated with the vapor of the liquid 184, as well as partially scrubbing the second syngas 20 of the slag/particulate mixture 50.

As shown in FIG. 6, a transition portion 204 may be included between the indirect heat exchange portion 202 of the cooling zone 19 and the quench portion 200 to facilitate channeling the second syngas 20 and the slag/particulate mixture 50 from the indirect heat exchange portion 202 into the quench portion 200. In certain embodiments, the transition portion 204 may have a wall 205 and a cone 206 that contain, and direct, the second syngas 20 and the slag/particulate mixture 50 such that they pass through the transition portion 204 into the quench portion 200. One or more portions of the wall 205 and the cone 206 may be cooled using a cooling fluid, such as the coolant 128 used in the cooling tubes 120, and may, for instance, be integral with the cooling tubes 120 used in the portion of the cooling zone 19 upstream of the transition portion 204. The wall 205 and the cone 206 may additionally or alternatively be protected from high-temperature exposure with an insulating material, such as shown by an insulating layer 207 attached to the cone 206.

The quench portion 200 downstream of the transition portion 205 may include a quench ring 208, a dip tube 209, a draft tube 210, the sump 180, a quench exit nozzle (e.g., the syngas outlet 190), and the solids outlet 186. The sump 180 may be a continuation of a wall of the cylindrical vessel 110, and the dip tube 209 may extend downward from the quench ring 208 into the liquid 184 of the sump 180. Further, the dip tube 209 may be concentrically aligned with the draft tube 210. The draft tube 210 has an inner diameter 211 that is larger than an outer diameter of the dip tube 209 such that the draft tube 210 surrounds the dip tube 209. A draft tube bottom end 212 may terminate below a dip tube bottom end 213. In certain embodiments, the draft tube bottom end 212 may also be in direct contact with the liquid 184 of the sump 180. A draft tube top end 214 may terminate below an interface between the dip tube 209 and the cone 207. The resulting alignment between the dip tube 209 and the draft tube 210 forms an annular space 215 around the outside of dip tube 209. In addition, one or more quench liquid makeup lines 216 may be connected to the quench ring 208.

In operation, the second syngas 20 and the slag/particulate mixture 50 may pass from the indirect heat exchange portion 202 of the cooling zone 19 through a transition portion inlet 217, exiting a transition portion 218 through the quench ring 208. The quench ring 208 may serve as a manifold that is both cooled by and distributes quench liquid makeup 219 supplied through the one or more quench makeup lines 216 over an inner surface 220 of the dip tube 209. The second syngas 20 and the slag/particulate mixture 50 may then pass down the dip tube 209 and enter the sump 180, where the second syngas 20 and the slag/particulate mixture 50 may mix with the quench liquid makeup 219 and the sump liquid 184. This mixing may result in the rapid cooling of the second syngas 20 and the production of a
syngas mixture 221 of the now cooler, lower particulate content second syngas 20 and the sump water 184. Hydraulic forces coupled with the geometry of the quench portion 200 may force the syngas mixture 221 to travel up through an annular space 215, and upon exiting the annular space 215, a portion of entrained liquid 222 may separate from the syngas mixture 221 resulting in a syngas mixture 223 with reduced particulate and entrained liquid contents that exits the sump 180 via the syngas outlet 190 (e.g., a syngas exit nozzle). Particulates thus separated from the second syngas 20 in the quench portion 200 and excess water may be removed via the solids outlet 186, and the now quenched syngas 223 may undergo further treatment before use.

[0050] In an alternative embodiment, depicted in FIG. 7, the second syngas 20 and associated particulates (e.g., the slag/particulate mixture 50) may undergo partial quenching wherein the degree of cooling and particulate separation may be less than might occur in the embodiment depicted in FIG. 6. In this alternative embodiment, the quench portion 200 includes a partial quench chamber 224 and a solids separation section 225, a solids transfer tube 226, and the sump 180.

[0051] Similar to transition portion 218 of FIG. 6, the partial quench chamber 224 may be defined by a partial quench inlet 227, a partial quench wall 228, a partial quench cone 229, and a partial quench outlet 230. The partial quench chamber 224 may also include cooling tubes (e.g., the cooling tubes 120), which may be insulated with a high temperature insulating material 231. However, the partial quench chamber 224 also includes one or more partial quench medium supply lines for injecting partial quench medium 232 through one or more partial quench medium nozzles 233. The solids separation section 225 is located immediately below, and is fluidly connected, to the partial quench chamber 224 via the partial quench outlet 230, and may include a solids separation wall 234 and a solids separation cone 235. The solids separation section 225 also includes a solids separation outlet 236 through the solids separation cone 235 and at least one partial quench syngas outlet 237 that is in fluid communication with the syngas outlet 190. The solids transfer tube 226 may provide a fluid connection between solids separation outlet 236 and the sump 180.

[0052] In operation, the second syngas 20 and the slag/particulate mixture 50 from the indirect heat exchange portion 202 of the cooling zone 19 flows into the partial quench chamber 224 through the partial quench inlet 227. In this way, the second syngas 20 may mix with the partial quench medium 232 supplied to the partial quench chamber 224 through the one or more sets of partial quench medium supply lines and the partial quench medium nozzles 233. In certain embodiments, the partial quench medium 232 includes gaseous or vapor streams, such as recycle syngas, recycle CO2, or superheated steam, that are sufficiently above their respective dew points that condensation will be prevented when the partial quench medium 232 is (1) injected into partial quench chamber 224 and (2) mixes with second syngas 20 and slag/particulate mixture 50. Such prevention may be important in avoiding fouling associated with the feedstock ash both within and downstream of partial quench chamber 224. After thorough mixing in partial quench chamber 224, the partially quenched second syngas 238, including the slag/particulate mixture 50, flows into the solids separation section 225 through the partial quench chamber outlet 230. The partially quenched second syngas 238 having a reduced portion of particulates (e.g., the slag/particulate mixture 50) is drawn off a side of the particulate separation section 225 through the partial quench syngas outlet 237. The particulates (e.g., slag/particulate mixture 50) separated from the partially quenched second syngas 238 are discharged via the solids separation outlet 236 and flow into the sump 180 via the solids transfer tube 226. In some embodiments, partial quench chamber 224 and particulate separation section 225 may be combined. In still other embodiments, solids transfer tube 226 may include a liquid supply and distribution manifold similar to quench liquid makeup 208 and quench ring 206 that supplies and distributes liquid makeup for continuously washing the inside surface of transfer tube 226 and cooling slag/particulate mixture 50.

[0053] To minimize the amount of particulates within the second syngas 20, in certain embodiments, the gasification system 10 may alternatively include a particulate separation system interposed between the upstream gasifier 12 and the downstream integrated reactor-syngas cooler 16. The particulate separation system may remove particulates (e.g., the slag/particulate mixture 50 and unreacted feedstock) generated during gasification of the feedstock 42, thereby reducing the amount of particulates flowing through the integrated reactor-syngas cooler 16 and decreasing fouling of heat transfer surfaces (e.g., the cooling tubes 120). For example, a two-stage particulate removal system similar to that disclosed in U.S. patent application Ser. No. 13/833,179, which is incorporated by reference here in its entirety, may be interposed between gasifier 12 and the integrated reactor-syngas cooler 16 to facilitate the removal of the slag/particulate mixture 50 from the second syngas 20. FIG. 8 illustrates a gasification system (e.g., the gasification system 10) including a two-stage particulate removal system 242. In the illustrated embodiment, the gasification system 10 includes the gasifier 12 including a reactor 243, a feed injector 244 for injecting the feedstock 42 and other feeds (e.g., the gasifying agent 44; the moderator 52, steam 48; water; and/or reactive gas, such as CO2) into the reactor 22. The gasifier 12 also includes a plenum chamber 245, which includes a hot side draw-off line 246 for removing hot syngas from the plenum chamber 245, and a gasifier quench chamber 247. The reactor 243 may be a substantially cylindrical steel pressure vessel 248, an upper portion of which is lined with the protective barrier 170 (e.g., refractory material) having an inner surface 250 that defines a reaction chamber 252 and the plenum chamber 245. The reaction chamber 252 and the plenum chamber 245 are connected via a throat 253 that connects a bottom 254 of the reaction chamber 252 with a top 255 of the plenum chamber 245. A bottom 256 of the plenum chamber 245 is connected to the quench ring 208, to which a stream of the quench liquid makeup 219 is fed via the one or more quench liquid makeup lines 216. The quench ring 208 is connected to the dip tube 209. The dip tube 209 extends a distance downwards into the quench chamber 247, which may be an un-lined cylindrical steel vessel 256 that forms part of a lower half of the gasifier vessel 248. The quench liquid makeup 219 from the quench ring 208 is distributed by the quench ring 208 around the inner surface 220 of the dip tube 209, and this film of quench liquid descends along the inner surface 220 and accumulates in a bottom portion 257 of the quench chamber 247 as a gasifier quench water pool 258. The quench water pool 258 is maintained at a constant level above the bottom of the dip tube 209 by withdrawing an appropriate flow rate of blowdown water from the quench chamber 247 via a blowdown line and control valve which are not shown. Connected to the gasifier 12,
via a flanged connection 260, is a transfer line 261 that contains an extension of the hot side draw-off line 246. The transfer line 261 is a cylindrical steel pipe 262 with a lining of the protective barrier 170, which defines an inner surface 263 of the hot side draw-off line 246. Connected to the transfer line 261 via a flanged connection 264 is a particle separation vessel 266. The particle separation vessel 266 includes a particle separation zone 267, a particle separation vessel quench chamber 268, and a particle separation vessel downstream connector 270. The particle separation zone 267 contains a further extension of the hot side draw-off line 246 that terminates in a downward facing nozzle 271 disposed above an orifice 272. The particle separation quench chamber 268 has a particle separation vessel quench ring 275, a particle separation vessel dip tube 274, and a particle separation quench ring water supply line 273, all of which are similar in form and function to the analogous parts in the quench chamber 247. Connected to the downstream end of the particle separation vessel 266, the downstream connector 270 is fluidly coupled to the integrated reactor-syngas cooler 16, which includes the reaction zone 18 and the cooling zone 19. The integrated reactor-syngas cooler reactor 18 includes a cylindrical steel pressure vessel 276 lined with the protective barrier 170 (e.g., a refractory material). Disposed about an inlet mixing region 277 of the integrated reactor-syngas cooler reactor 18 are the one or more feed injectors 140 for use in injecting additional feedstock 42 into the interior of the integrated reactor-syngas cooler reactor 18. In one embodiment, the one or more feed injectors 140 may be oriented perpendicular to a long axis (e.g., the axis 100) of the integrated reactor-syngas cooler 16. In an alternative embodiment, the one or more feed injectors 140 may be oriented at an acute angle with respect to the long axis (e.g., the axis 106) of the integrated reactor-syngas cooler 16. In another alternative embodiment, the feed injectors 140 may be oriented at an obtuse angle with respect to the axis 100 of the integrated reactor-syngas cooler 16. In a still further alternative embodiment, all of the feed injectors 140 may be oriented radially inwards towards the centerline of the integrated reactor-syngas cooler 16 (e.g., along radial axis 102). In yet another alternative embodiment, the feed injectors 140 may be oriented at an angle with respect to the radial direction (e.g., radial axis 102) in order to induce a swirling flow about the long axis. As should be appreciated, the feed injectors 140 may have any combination of angles with respect to the long axis (e.g., the axis 106) and/or with respect to the radial direction (e.g., the radial axis 102) in order to provide a combination of orientations which optimizes the injection of the feedstock 42 and the mixing of the feedstock 42 with the flow of gas through the integrated reactor-syngas cooler 16. Located immediately downstream of the inlet mixing region 277 of the integrated reactor-syngas cooler reactor 18, and fluidly connected to it, is a residence time region 278 of the integrated reactor-syngas cooler reactor 18. The inlet mixing region 277 provides space for the first syngas 14 and the additional feedstock 42 to rapidly and effectively mix. The residence time region 278 provides sufficient time for the first syngas 14 and the additional feedstock 42 to react. Located immediately downstream of integrated reactor-syngas cooler reactor 18, and fluidly connected, is the cooling zone 19. The cooling zone 19 is a cylindrical steel vessel 279 that includes the one or more cooling tubes 120, through which flows the coolant 128 such as water, boiler feed water, steam, heat transfer fluid or some combination thereof. The cooling tubes 120 may be arranged in various combinations in order to optimize the desired amount of syngas cooling that occurs within the cooling zone 19. For example, in one embodiment, shown on the left hand side of cooling zone 19 in FIG. 8, one cooling tube 120 is shown out of a plurality of cooling tubes 120 arranged circumferentially about the inner surface of the cylindrical steel vessel 279 in order to form a cylindrically-shaped cooling tube cage. The coolant 128, e.g., boiler feed water, enters the tube cage via the coolant inlet 174 and a coolant inlet tube header 280 positioned at a cooling region bottom end 281. After recovering heat in the cooling zone 19, heated coolant 128, e.g., steam, exits the tube cage via coolant exit header 282 and the coolant outlet 174 positioned at a cooling region top end 283. In an alternative embodiment, a number of vertical platens 284 are added to the cylindrically-shaped tube cage. The cooling zone 19 may include any number of the platens 284 such as 4, 6, 8, 10, 12, 18, 24 or any other suitable number. The platens 284 may extend from the tube cage radially (e.g., the radial axis 102) inwards to the direction of the centerline axis (e.g., the axial axis 100) of the vessel 279. In one embodiment, the platens 284 stop short of extending all the way to the centerline axis 100 in order to provide an open passage along the centerline axis 100 of the vessel 279. In an alternative embodiment, the platens 284 extend all the way to the centerline axis 100 in order to make maximal use of the volume within the cooling zone 19. As with the cylindrical tube cage, cooling fluid enters the platens 284 via a platen bottom inlet (not shown) and a platen bottom inlet header 285. After recovering heat in the cooling zone 19, heated cooling fluid (e.g., the coolant 128) exits the platens 284 via a platen top exit header 286 and a platen top exit line (not shown). It should be noted that, as shown in FIG. 8, the inlet mixing region 277 and the residence time region 278 of the integrated reactor-syngas cooler reactor 18 and the syngas cooling zone 19 are not necessarily drawn to scale and, in actual practice, relative sizes may differ from what is shown in FIG. 8. For example, the integrated reactor-syngas cooler reactor 18 may be shorter, the same size as, or longer than cooling zone 19. Likewise, within the integrated reactor-syngas cooler reactor 18, the residence time region 278 may be shorter, the same size as or longer than the inlet mixing region 277. The relative lengths of the inlet mixing region 277, the residence time region 278, and the syngas cooling zone 19 may be varied in order to produce the desired relative amounts of feedstock reaction and syngas cooling. Furthermore, similar to the embodiments shown in FIGS. 6 and 7, it should be understood, that cooling zone 19 may also be followed by quench or partial quench cooling, depending on the specific application of the syngas. For embodiments incorporating the former, the second syngas 20 and the slag/particulate mixture 50 may first need to be redirected into a vertically downward flow to ensure effective introduction into the quenching medium.
which accumulate on the inner surface 250 of the protective barrier 170, and some of which become entrained in the downward flow of the first syngas 14. The molten slag that accumulates on the inner surface 250 runs down the inner surface 250 and exits the throat 253 as medium to large droplets, which continue downwards into the dip tube 209 and into the gasifier quench water pool 258 where they are rapidly cooled to form solidified particles of the slag/particulate mixture 50. The solidified slag/particulate mixture 50 flows into a slag handling system (not shown) via a gasifier bottom exit nozzle 290. The remaining fine droplets of the molten slag/particulate mixture 50 exit the reaction chamber 252 entrained in the first syngas 14. Other fine particulates (e.g., char, unreacted feedstock, etc.) may also be entrained in the first syngas 14. After passing through the throat 253, the flow of the first syngas 14 and the entrained fine particulates enter the first stage of particle separation in the plenum chamber 245. Inside the plenum chamber 245, the flow of the first syngas 14 is split in two directions. A smaller portion of the flow, e.g., approximately 1%, 2%, 5%, 10%, 15% or 20%, continues downwards into the dip tube 209 and into the quench water pool 258 where it is rapidly cooled and where the medium to large size molten slag droplets and some of the other entrained particulates are separated from the first syngas 14. The downwards flow of the first syngas 14 assists particulates of all sizes to follow a downwards path into the dip tube 209 and into the quench water pool 258 so that the particulates (e.g., the slag/particulate mixture 50) can be removed from the first syngas gas 14. After passing downwards into the quench water pool 258, the small flow of the first syngas 14 reverses direction, exits the upper surface of the quench water pool 258 and exits the gasifier quench chamber 247 as quenched syngas stream 292 via exit nozzle 294. The larger portion of the first syngas 14 that remains is forced to make a very sharp turn to enter the upwards sloping inlet portion of the hot side draw-off line 246. Because only the finest entrained particulates in the slag/particulate mixture 50 (e.g., fine droplets of molten slag and fine particles of char or unreacted feedstock) are able to follow the streamlines and make such as sharp turn into the inlet of the hot side draw-off line 246, the sharp turn serves as an effective first stage particle removal step, removing approximately 80% to approximately 99% of the molten slag and other particles from the first syngas 14 exiting the gasifier throat 253. For example, the first stage particle removal step removes approximately 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% of the molten slag and other particulates from the first syngas 14. The removed molten slag droplets and other particles continue by momentum into the dip tube 209 and the quench chamber 247. Once inside the hot side draw-off line 246, the first syngas 14 with the reduced load of fine molten slag droplets and other particles continues through the transfer line 261 and enters the particle separation zone 267 of the particle separation vessel 266. This is the second stage of particle separation. Once inside the particle separation zone 267, the first syngas 14 and the remaining entrained fine molten slag droplets, as well as any other particulates (e.g., char) still in the first syngas 14, are accelerated downwards towards the orifice 272 via the nozzle 271. The acceleration drives the remaining fine droplets and particles down through the orifice 272 and into the particle separation vessel dip tube 274 and a particle separation vessel quench water pool 296. A small portion of the first syngas 14, e.g., 1% 2%, 5%, 10%, 15% or 20%, passes through the orifice 272 to assist the flow of the remaining fine molten slag droplets and particles down into the particle separation vessel quench water pool 296. The fine molten slag droplets rapidly cool and solidify in the water and exit the particle separation quench chamber 268 as solidified slag stream 298 via quench bottom exit nozzle 299. A small portion of the first syngas 14 passes through the quench water pool 296 and exits the particle separation quench chamber 268 via syngas exit nozzle 297 as particle separation vessel quenched syngas 295. The larger, remaining portion of the first syngas 14 that was accelerated through the nozzle 271 makes a 180 degree turn, flows around the outside of the nozzle 271 and the extension of the hot side draw-off line 246 and flows upwards through the particle separation vessel downstream connector 270. Because of the high velocity to which the nozzle 271 accelerates the first syngas 14 and the very sharp 180 degree turn that the larger portion of the first syngas 14 that was accelerated by the nozzle 271 is subjected to, essentially all of the fine molten slag droplets and other fine particles that were accelerated through the nozzle 271 along with the first syngas 14 are driven downwards into the particle separation vessel dip tube 274 and the particle separation vessel quench water pool 296. Thus, the two stages of the particle separation are effective in removing essentially all of the entrained molten slag and other fine particulates from the first syngas 14 produced in the gasifier 12. As a result, the first syngas 14 that flows upwards through the particle separation vessel downstream connector 270 and into the integrated reactor-syngas cooler 16 is virtually droplet and particle free.

[0055] The first syngas 14 generated in the gasifier 12, having been cleaned of virtually all entrained molten slag droplets and other entrained particles by the two-stage particle separation process 242 of the gasification system 240, flows upwards through the particle separation vessel downstream connector 270 and enters the inlet mixing region 277 of the integrated reactor-syngas cooler reactor 18. In one embodiment, the one or more feed injectors 140 disposed about the inlet mixing region 277 inject additional feedstock 42 into the upward rising flow of the first syngas 14. In another embodiment, the feed injectors 140 may also inject additional feeds, such as steam or water or a reactive gas, such as CO₂, or a fuel gas recycled from elsewhere in the plant. The number, location, and orientation of the one or more feed injectors 140, which was described above, is configured to optimize the amount of mixing that occurs in the inlet mixing region 277 between the first syngas 14 and the additional feedstock 42 as well as other feeds, if desired. Undesiredly, the thermal energy contained within high temperature first syngas 14 drives endothermic gasification reactions which convert the additional feed 42 into additional syngas (e.g., the second syngas 20). The reacting mixture of the additional feedstock 42, additional feed materials (if present), the first syngas 14, and newly produced additional syngas (e.g., the second syngas 20) flow from the inlet mixing region 277 of the integrated reactor-syngas cooler reactor 18 into the residence time region 278 where the reacting mixture continues to react to produce the second syngas 20. As the endothermic reactions that convert the additional feedstock 42 into the second syngas 20 absorb thermal energy from the reacting mixture, the temperature of the mixture decreases in direct relation to how much additional feedstock 42 has been converted to the second syngas 20. As the temperature of a gaseous mixture containing CO, H₂, CO₂, and H₂O is cooled,
the equilibrium of the water gas shift reaction involving those four components changes in such a way that the production of H₂ and CO₂ becomes more favored. Likewise, as the temperature of a gaseous mixture containing CO, H₂, CH₄, and H₂O is cooled, the equilibrium of the methanation reaction involving those four components changes in such a way that the production of CH₄ and H₂O becomes more favored. Thus, as the temperature of the reacting mixture continues to fall as gasification progresses, the composition of the reacting mixture may become increasingly enriched in H₂ and CH₄. Therefore, the second syngas 20 may have a composition that differs from the first syngas 14. Specifically, the second syngas 20 may be enriched in H₂ and/or CH₄ compared with the first syngas 14. The extent to which the second syngas 20 will become enriched in H₂ and/or CH₄ within the integrated reactor-syngas cooler reactor 18 depends on several factors including the temperature, flow rate, and composition of the first syngas 14, the temperature, flow rate, and composition of the additional feedstock 42 injected through the one or more feed injectors 140, and the temperature and composition of any additional feeds that are injected along with additional feedstock 42, and the diameters and lengths of the inlet mixing region 277 and residence time region 278 in which all the materials react. As should be appreciated, these aforementioned parameters may be varied in order to exercise a wide degree of control over both the composition and the temperature of the second syngas 20 exiting the residence time region 278 of the integrated reactor-syngas cooler reactor 18. [0056] The temperature of the second syngas 20 leaving the integrated reactor-syngas cooler reactor 18 may be lower than the temperature of the first syngas 14 entering the integrated reactor-syngas cooler reactor 18. The decrease in the temperature of the second syngas 20 compared with the temperature of the first syngas 14 may be directly related to the amount of endothermic reaction of the additional feedstock 42 that was allowed to occur within the integrated reactor-syngas cooler reactor 18. Upon exiting the residence time region 278, the second syngas 20 flows immediately into the cooling zone 19 of the integrated reactor-syngas cooler 16. Inside the cooling zone 19, the second syngas 20 is further cooled by indirect heat exchange with the cooling fluid (e.g., the coolant 128) circulating in the cooling tubes 120. The final temperature of the second syngas 20 leaving the cooling zone 19 is directly related to the temperature, composition, and flow rate of the second syngas 20 entering the cooling zone 19, as well as the surface area and arrangement of the cooling tubes 20 within the cooling zone 19. By providing more surface area and a more effective arrangement of the cooling tubes 120, the second syngas 20 may be brought to a final exit temperature that is lower than the case where less surface area and a less effective arrangement of the cooling tubes 120 is provided. It will be appreciated that, as the second syngas 20 passes through the cooling zone 19 and decreases in temperature from its inlet temperature to its final outlet temperature, the components including the second syngas 20 may continue to react, for example, to convert any residual, unreacted additional feedstock 42 from the integrated reactor-syngas cooler reactor 18 into additional syngas. Furthermore, the equilibrium concentrations of reactions such as the water gas shift reaction and the methanation reaction may continue to shift in the direction that favors the generation of even more H₂ and CH₄ than what was present in the syngas leaving the integrated reactor-syngas cooler reactor 18 (e.g., the second syngas 20). However, at some point, the temperature of the second syngas 20 may decrease to a point where the rates of reaction may be so slow that no appreciable additional reaction may occur. At that point, the composition of the second syngas 20 may stabilize at a final exit composition. [0057] It will be further appreciated that the fouling behavior of the cooling zone 19 may be positively affected by the manner in which the integrated reactor-syngas cooler reactor 18 is operated. Although the two-stage particle separation system 242 interposed between the gasifier 12 and the integrated reactor-syngas cooler 16 removed the slag/particulate mixture 50 (molten slag droplets, unreacted feedstock, char, etc.) from the first syngas 14, additional particulates are introduced into the integrated reactor-syngas cooler 16 via the feed injectors 140 disposed about the inlet mixing region 277 of the integrated reactor-syngas cooler reactor 18. Furthermore, as the additional feedstock 42 is gasified by the hot first syngas 14, at least a portion of the non-gasifiable mineral matter in the feedstock 42 may form droplets of molten ash which may be sticky and have a tendency to adhere to and foul the heat exchange surfaces of the cooling tubes 120 in the downstream cooling zone 19. However, by providing enough length in the residence time region 278 of the integrated reactor-syngas cooler reactor 18, and by controlling the operating parameters, the temperature of the second syngas 20 may be at least sufficiently decreased so that any entrained particulates, such as droplets of molten ash, cool to the point where they solidify and form solid particles of slag that neither adhere to nor foul the downstream heat exchange surfaces in the cooling zone 19. Thus, by properly designing and operating the integrated reactor-syngas cooler reactor 18 of the integrated reactor-syngas cooler 16, it may be possible to operate the cooling zone 19 with limited tendency to foul and/or plug. [0058] Present embodiments also include a method that utilizes the gasification system 10 to supply additional feedstock to an integrated reactor-syngas cooler reactor 18, thereby generating a CH₄ or H₂ enriched syngas. FIG. 9 illustrates a flow diagram of a method 300 by which a gasification system (e.g., the gasification system 10 described above) may produce a CH₄ or H₂ enriched syngas (e.g., the second syngas 20) in an integrated reactor-syngas cooler reactor 18. The method 300 includes supplying the gasifier 12 with the feedstock 42 (block 304), and gasifying the feedstock 42 to generate the first syngas 14 (block 306), as described above with reference to FIGS. 1 and 2. The method 300 also includes directing the first syngas 14 to the integrated reactor-syngas cooler 16 (block 308) and providing the additional feedstock 142 and the moderator 52 to the integrated reactor-syngas cooler 16 (block 310). As should be noted, the first syngas 14 may be processed in a two-stage particulate removal system 242 prior to flowing into the integrated reactor-syngas cooler 16, as discussed above with reference to FIG. 8. [0059] While in the integrated reactor-syngas cooler 16, the additional feedstock 142 is gasified in the integrated reactor-syngas cooler reactor 18 (block 314). As discussed above, the amount of the gasification components (e.g., the additional feedstock 142 and/or the moderator 52) may be adjusted depending on a desired composition of the second syngas 20. For example, in certain embodiments, an amount of the moderator 52 (e.g., steam) may be between approximately 10% to approximately 30% by weight less than an amount of the additional feedstock 142. This may favor methanation of the additional feedstock 142 and reduce gasification products generated by the water gas and water-gas-shift reactions (e.g.,
CO, CO₂, and H₂). Conversely, in other embodiments, the amount of the moderator 52 may be between approximately 10% to approximately 30% by weight more than an amount of the additional feedstock 142. Therefore, the water gas and water-gas-shift reactions may be favored and the second syngas 20 may be enriched with H₂. Accordingly, the method 300 further includes adjusting an amount of gasification components (e.g., the moderator 52 and/or the additional feedstock 142) to enrich the second syngas 20 with CH₄ or H₂ (block 318). For example, as discussed above, the controller 60 may control valves 66 and 68 to adjust the amount of feedstock (e.g., feedstock 42 and 142) supplied to the gasifier 12 and the integrated reactor-syngas cooler reactor 18, respectively. Additionally, the controller 60 may control valves 64 and 70 to adjust amounts of the gasifying agents 44 and the moderator 52, respectively.

[0060] The method 300 also includes directing the second syngas through the cooling zone 19 within the integrated reactor-syngas cooler 16 (block 320). While in the cooling zone 19, the coolant 128 cools the second syngas 20 via indirect heat exchange (block 322). In addition to cooling the second syngas 20, the cooling zone 19 facilitates separation of particulates (e.g., the slag 50) from the second syngas 20, as discussed above. Once cooled, the second syngas 20 may be processed (e.g., purified) prior to use.

[0061] As described above, certain embodiments of the integrated reactor-syngas cooler 16 may include the integrated reactor-syngas cooler reactor 18 disposed above or below the cooling tubes 120. The integrated reactor-syngas cooler reactor 18 is configured to receive the first syngas 14 from the gasifier 12 and additional gasification components (e.g., the additional feedstock 142 and/or the moderator 52) from one or more feed injector nozzles 140 disposed on the upper cylindrical shell portion 114 or disposed about the inlet mixing region 277. The additional gasification components may utilize heat from the first syngas 14 for gasification, thereby generating the second syngas 20. By adjusting the amount of gasification components supplied to the integrated reactor-syngas cooler reactor 18, the CO/H₂ ratio may be adjusted. In this way, the second syngas 20 may be enriched with either CH₄ or H₂.

[0062] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

1. A system, comprising:
   an integrated reactor-syngas cooler configured to gasify a feedstock, wherein the integrated reactor-syngas cooler comprises:
   a reaction zone configured to receive a first syngas and the feedstock, and to gasify the feedstock to generate a second syngas, wherein the second syngas has a composition different from the first syngas;
   one or more feed injectors disposed in the integrated reactor-syngas cooler and configured to supply the feedstock to the reaction zone; and
   a cooling zone disposed downstream of the reaction zone and comprising one or more cooling tubes, wherein the cooling zone is configured to receive and cool the second syngas.

2. The system of claim 1, comprising a gasifier fluidly coupled to the integrated reactor-syngas cooler, wherein the gasifier is configured to generate the first syngas.

3. The system of claim 1, wherein the second syngas is at least one of quenched or partially quenched in the cooling zone by combination with a quenching or partial quenching agent, respectively, before discharge from the integrated reactor-syngas cooler.

4. The system of claim 3, wherein the quenching or partial quenching occurs in a downstream portion of the cooling zone.

5. The system of claim 3, wherein the quenching agent is comprised of at least one of liquid water and a solvent, and the partial quenching agent is comprised of at least one of nitrogen, recycle syngas, carbon dioxide and superheated steam.

6. The system of claim 1, wherein the cooling tubes are aligned with an integrated reactor-syngas cooler centerline such that the cooling tubes are axially and circumferentially arranged over at least a portion of the cooling region.

7. The system of claim 1, wherein the cooling tubes circumferentially spiral about an integrated reactor-syngas cooler centerline to form a helical configuration over at least a portion of the integrated reactor-syngas cooler.

8. The system of claim 1, wherein at least a portion of the reaction zone of the integrated reactor-syngas cooler comprises a protective barrier.

9. The system of claim 1, comprising a particle separation system fluidly coupled to the reaction zone, wherein the particle separation system is configured to receive the first syngas from a gasifier disposed upstream of the reaction zone to enable separation of at least one of slag or particulates from the first syngas before directing the first syngas to the reaction zone.

10. The system of claim 1, comprising a controller configured to control an amount of at least one of the feedstock, or a moderator, or a reactive gas, or a combination thereof, supplied to the reactor to enrich the second syngas with methane or hydrogen.

11. The system of claim 1, wherein the one or more feed injectors are circumferentially distributed in the integrated reactor-syngas cooler, and wherein the one or more feed injectors are configured to direct the feedstock axially, circumferentially or toward an integrated reactor-syngas cooler centerline axis within the integrated reactor-syngas cooler.

12. A method, comprising:
   gasifying a first feedstock in a gasifier to generate a first syngas;
   directing the first syngas to an integrated reactor-syngas cooler fluidly coupled to the gasifier;
   supplying a second feedstock to the integrated reactor-syngas cooler, wherein the integrated reactor-syngas cooler comprises a reaction zone configured to gasify the second feedstock by reaction with the first syngas to generate a second syngas; and
   adjusting an amount of the second feedstock supplied to the reaction zone of the integrated reactor-syngas cooler to adjust a composition of the second syngas.
13. The method of claim 12, comprising adjusting an amount of at least one of a moderator and a reactive gas supplied to the reaction zone to adjust the composition of the second syngas.

14. The method of claim 12, wherein the first feedstock and the second feedstock are the same.

15. The method of claim 12, wherein the first feedstock and the second feedstock are different.

16. The method of claim 12, comprising separating at least one of slag and particulates from the first syngas prior to directing the first syngas into the reaction zone of the integrated reactor-syngas cooler.

17. The method of claim 12, comprising cooling the second syngas in a cooling zone of the integrated reactor-syngas cooler.

18. The method of claim 12, wherein the second syngas is enriched with methane or hydrogen.

19. A system, comprising:
   a controller, comprising:
   one or more tangible, non-transitory, machine-readable media collectively storing one or more sets of instructions; and
   one or more processing devices configured to execute the one or more sets of instructions to monitor or control operations of the system, wherein the one or more sets of instructions are configured to:
   supply a first feedstock to a gasifier and a second feedstock to a reaction zone of an integrated reactor-syngas cooler disposed downstream of the gasifier, wherein the gasifier is fluidly coupled to the reaction zone of the integrated reactor-syngas cooler and configured to gasify the first feedstock to generate a first syngas; and
   gasify the second feedstock in the reaction zone of the integrated reactor-syngas cooler to generate a second syngas, wherein the reaction zone of the integrated reactor-syngas cooler utilizes heat from the first syngas to gasify the second feedstock; and
   adjust an amount of the second feedstock in the reaction zone of the integrated reactor-syngas cooler to enrich the second syngas with methane or hydrogen and adjust the temperature of the second syngas.

20. The system of claim 20, wherein the controller adjusts an amount of moderator or reactive gas in the reaction zone of the integrated reactor-syngas cooler to modify the composition of the second syngas.