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(54) **SYSTEM AND METHOD FOR CONTINUOUS SLAG HANDLING WITH DIRECT COOLING**

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(57) **ABSTRACT**

A system includes a quench chamber configured to continuously receive a mixture of a gas and slag, and a downstream end portion coupled to the quench chamber. The quench chamber includes a quench sump configured to continuously separate the gas from the slag in the mixture via a quench liquid. The downstream end portion is configured to continuously convey a slag slurry to a depressurization system. The downstream end portion includes a cooling system configured to directly cool the slag slurry with a cooling fluid, and the slag slurry includes the separated slag and at least a portion of the cooling fluid

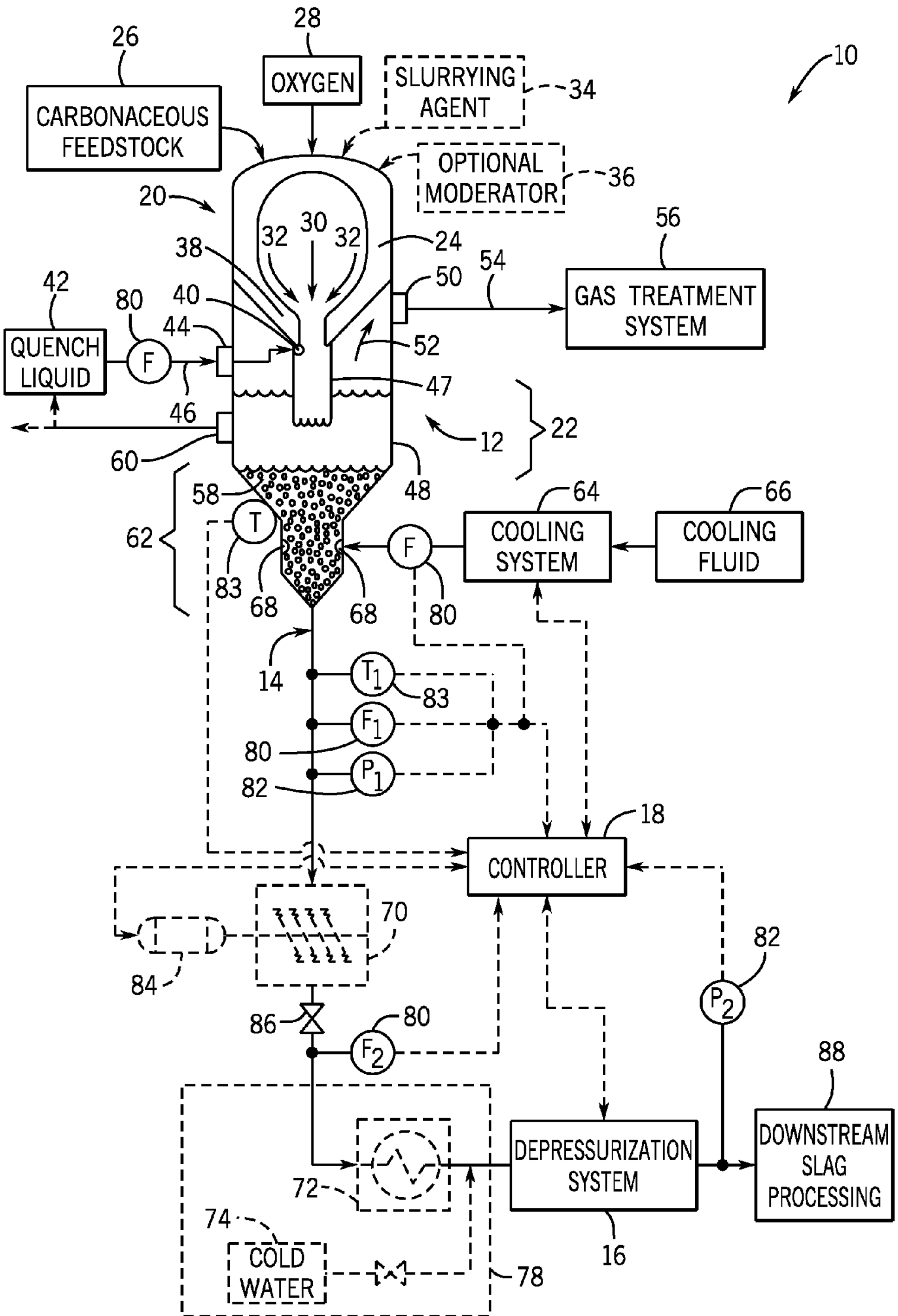
CARBONACEOUS FEEDSTOCK
OXYGEN
SLURRYING AGENT
OPTIONAL MODERATOR
GAS TREATMENT SYSTEM
QUENCH LIQUID
COOLING SYSTEM
COOLING FLUID
CONTROLLER
DEPRESSURIZATION SYSTEM
DOWNSTREAM SLAG PROCESSING
COLD WATER

FIG. 1

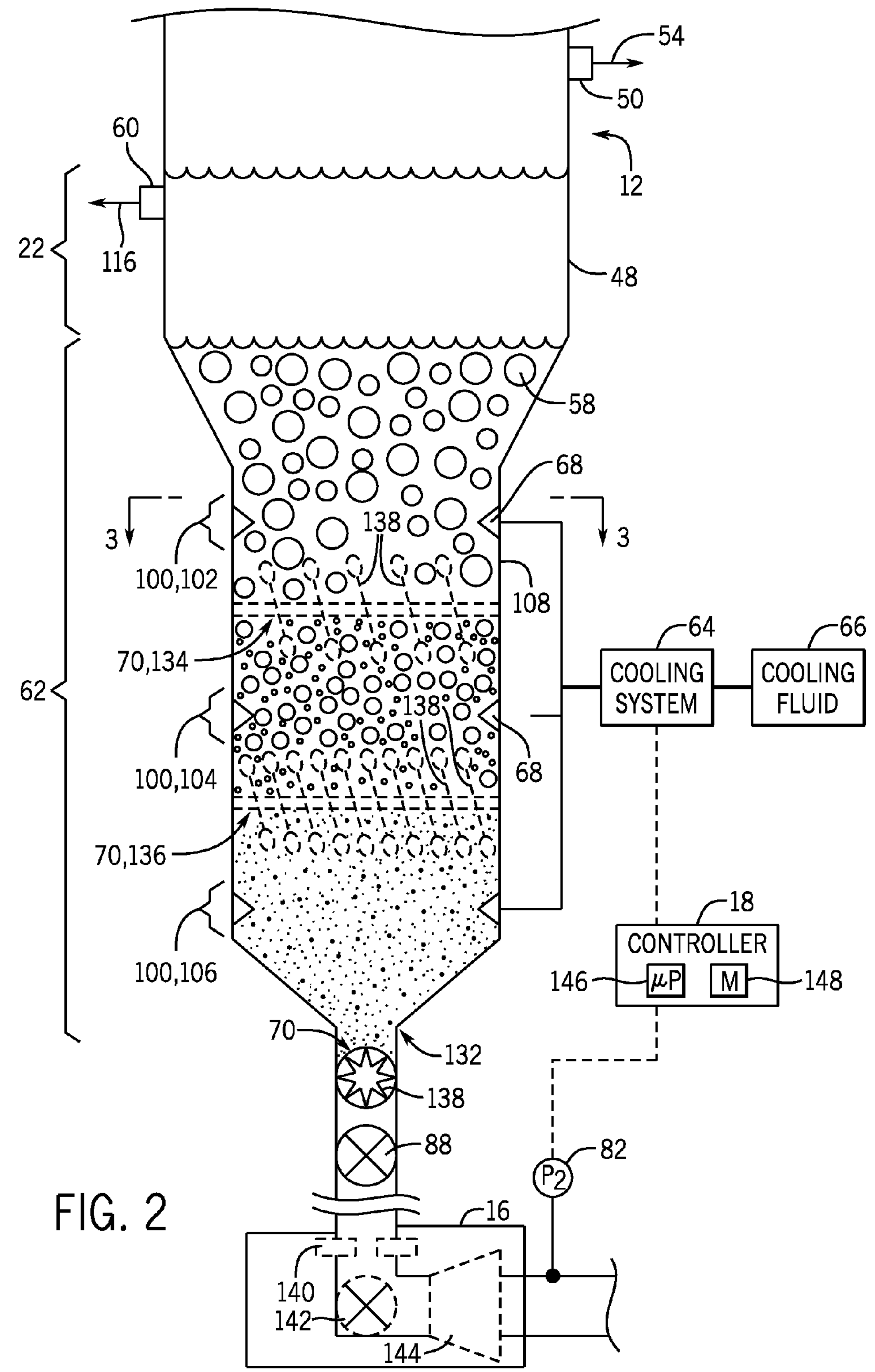
54
50
60
12
22
116
48
58
68
3
3
138
100,102
108
70,134
64
66
COOLING SYSTEM
COOLING FLUID
62
100,104
138
68
70,136
18
CONTROLLER
100,106
146
μP
M
148
70
132
138
88
82
P2
16
140
142
144

FIG. 2

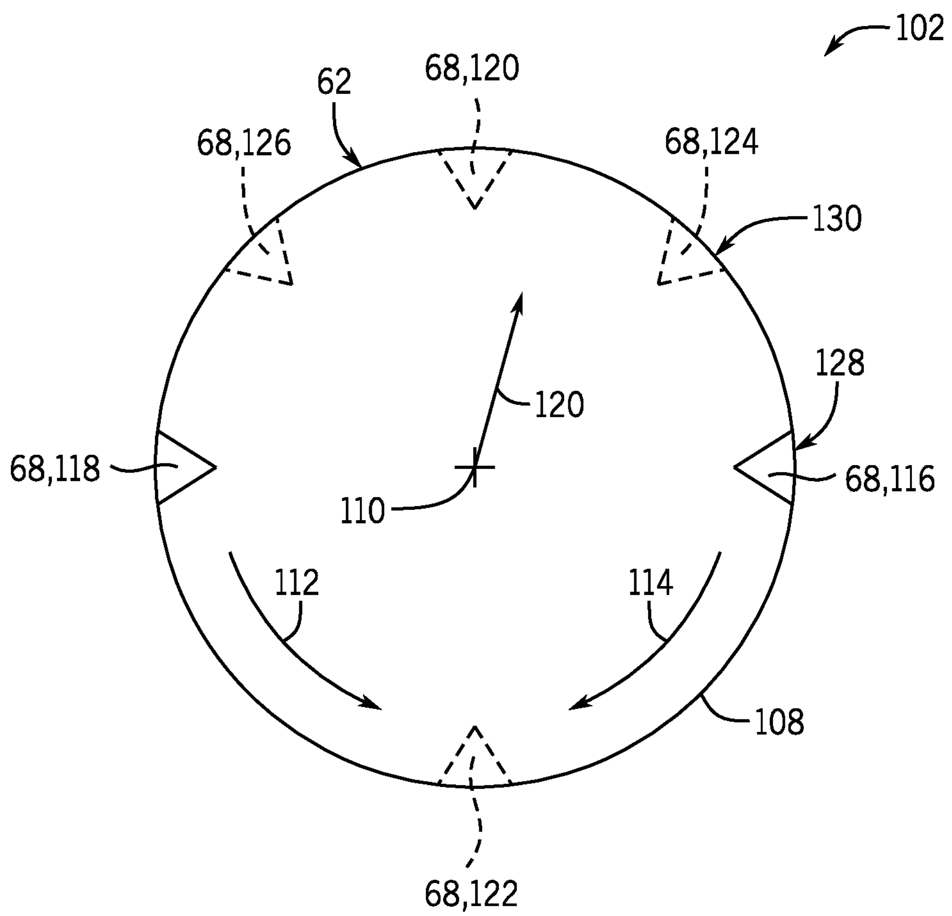
102
62
68,120
68,126
68,124
130
128
120
68,118
68,116
110
112
114
108
68,122

FIG. 3

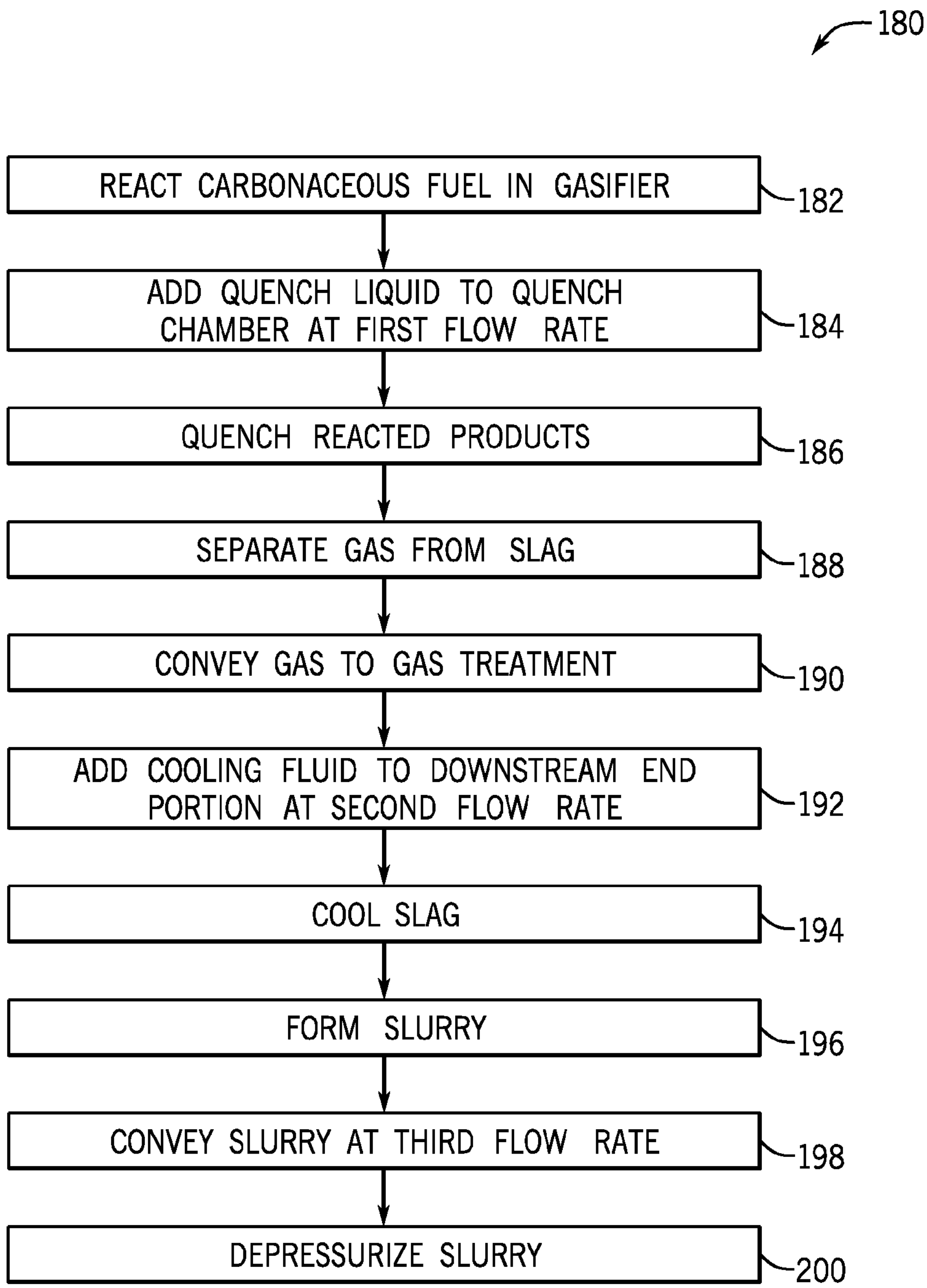
180
REACT CARBONACEOUS FUEL IN GASIFIER
182
ADD QUENCH LIQUID TO QUENCH CHAMBER AT FIRST FLOW RATE
184
QUENCH REACTED PRODUCTS
186
SEPARATE GAS FROM SLAG
188
CONVEY GAS TO GAS TREATMENT
190
ADD COOLING FLUID TO DOWNSTREAM END PORTION AT SECOND FLOW RATE
192
COOL SLAG
194
FORM SLURRY
196
CONVEY SLURRY AT THIRD FLOW RATE
198
DEPRESSURIZE SLURRY
200

FIG. 4

SYSTEM AND METHOD FOR CONTINUOUS SLAG HANDLING WITH DIRECT COOLING

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH & DEVELOPMENT

[0001] This invention was made with Government support under contract number DE-FE0007859 awarded by the Department of Energy. The Government has certain rights in the invention.

BACKGROUND

[0002] The subject matter disclosed herein relates to a slag handling system, and, more particularly, to a continuous slag handling system.

[0003] An industrial process may utilize a slurry, or fluid mixture of solid particles suspended in a liquid (e.g., water), to convey the solid particles through the respective process. For example, partial oxidation systems may partially oxidize carbon-containing compounds in an oxygen-containing environment to generate various products and by-products. For example, gasifiers may convert carbonaceous materials into a useful mixture of carbon monoxide and hydrogen, referred to as synthesis gas or syngas. In the case of an ash-containing carbonaceous material, the resulting syngas may also include less desirable components, such as heavy ash or molten slag, which may be removed from the gasifier along with the useful syngas produced. Accordingly, the molten slag byproduct produced in the gasifier reactions may be directed into a gasifier quench liquid in order to solidify the molten slag and to create a slurry. Generally, this slurry is discharged from the gasifier at elevated temperatures and high pressures. The slurry discharged from the gasifier is depressurized to enable the disposal of, or the further processing of, the slurry. Unfortunately, heat exchangers that reduce the temperature of the slurry after discharge from the gasifier may have complex flow paths, may have relatively large foot prints, and/or may be susceptible to erosion or blockages due to slag accumulation.

BRIEF DESCRIPTION

[0004] 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.

[0005] In a first embodiment, a system includes a quench chamber configured to continuously receive a mixture of a gas and slag, and a downstream end portion coupled to the quench chamber. The quench chamber includes a quench sump configured to continuously separate the gas from the slag in the mixture via a quench liquid. The downstream end portion is configured to continuously convey a slag slurry to a depressurization system. The downstream end portion includes a cooling system configured to directly cool the slag slurry with a cooling fluid, and the slag slurry includes the separated slag and at least a portion of the cooling fluid.

[0006] In a second embodiment, a system includes a gasifier configured to react a carbonaceous feedstock into a mixture of a gas and slag. The gasifier includes a quench sump configured to continuously separate the gas from the slag in the mixture via a quench liquid, and the quench liquid is configured to flow through the quench sump at a first flow rate. The gasifier also includes a downstream end portion of the gasifier having a cooling system and a controller. The downstream end portion is configured to continuously convey a slag slurry to a depressurization system at a third flow rate approximately 15 percent or less of the first flow rate, the downstream end portion is configured to add a cooling fluid at a second rate to cool the slag slurry, and the slag slurry includes the slag and the cooling fluid.

[0007] In a third embodiment, a method includes separating slag from a gas, dispensing a cooling fluid into a downstream end portion of a gasifier, forming a cooled slag slurry from the slag and the cooling fluid, and conveying the cooled slag slurry substantially continuously through an exit of the downstream end portion. The temperature of the slag is greater than approximately 175 degrees C., and the cooling fluid is configured to decrease the temperature of the slag to less than approximately 70 degrees C.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] 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:

[0009] FIG. **1** is a schematic diagram of an embodiment of a continuous slag removal system;

[0010] FIG. **2** is a schematic diagram of an embodiment of a gasifier having a direct cooling system;

[0011] FIG. **3** is a cross-section of an embodiment of the direct cooling system, taken along line **3-3** of FIG. **2**; and

[0012] FIG. **4** is a flowchart illustrating a process for continuously handling the slurry in accordance with an embodiment.

DETAILED DESCRIPTION

[0013] 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.

[0014] 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.

[0015] Various industrial processes involve the handling of slurries. A slurry may include particulate solids dispersed in a fluid, such as water. In certain situations, the slurry is transported from a first location, or vessel, to a second location. The slurry may be depressurized and/or cooled during transport from the first location to the second location. For example, the reaction chamber of a partial oxidation system (e.g., a gasifier) may receive a carbonaceous feedstock (e.g., a slurry of carbonaceous particulate solids such as coal or biomass, a pneumatically-conveyed stream of particulate solids, a liquid, a gas, or any combination thereof) and an oxidant (e.g., high purity oxygen). In some embodiments, the reaction chamber may receive water (e.g., water spray or steam) to contribute to the slurry. The partial oxidation of the feedstock, the oxidant, and in some cases, the water, may produce a useful gaseous product and an ash or a molten slag byproduct. For example, a gasifier may receive the feedstock, the oxygen and the water to generate a synthetic gas, or syngas, and a molten slag. In certain cases, the molten slag may flow through the gasifier into a quench liquid, such as water, to create a slag slurry. The slag slurry discharged from the gasifier may be at a high gage pressure between approximately 1000 to 10,000 kilopascals (kPa). The slag slurry within the gasifier may be at a temperature between approximately 80 to 250 degrees C., (e.g., 175 to 475 degrees F.), between approximately 100 to 225 degrees C. (e.g., 212 to 440 degrees F.), or between approximately 150 to 200 degrees C. (e.g., 300 to 400 degrees F.) or more. Before the slag slurry is further processed or disposed of, the slag slurry may be depressurized to a lower pressure (e.g., atmospheric pressure). Depressurization of the slag slurry at elevated temperatures may cause vapor flash where at least a portion of the liquid (e.g., water) in the slag slurry evaporates. The disclosed embodiments discussed below cool the slag slurry to a temperature that substantially reduces the occurrence of vapor flash when the slag slurry is depressurized. For example, the disclosed embodiments may cool the slag slurry to a temperature less than approximately 70 degrees C. (e.g., 160 degrees F.). The slag slurry may be cooled without a heat exchanger or cooler downstream of the gasifier. The slag slurry is cooled upstream of the depressurization system by a cooling fluid (e.g., water). The cooling fluid may be injected into the slag slurry at a gage pressure greater than or approximately equal to the gage pressure of the slag slurry.

[0016] The disclosed embodiments convey the slag slurry in a continuous process, rather than a batch process. As may be appreciated, a continuous process may occupy less vertical space than a batch process (e.g., lock hopper) and may have lower costs than a batch process. In some embodiments, a continuous process may utilize less water than the batch process. Furthermore, as discussed in detail below, embodiments of the continuous process may increase control of the amount of water (e.g., cooling fluid) in the slag slurry relative to the batch process. Thus, the disclosed embodiments employ a depressurization system (e.g., liquid expansion system) to continuously remove the slag slurry and reduce the pressure, while also consuming less space. In some embodiments, the depressurization system generates power, such as via an expansion turbine. Therefore, certain embodiments may be referred to as slag slurry depressurizing systems, or more generally as slag slurry handling systems.

[0017] With the foregoing in mind, FIG. **1** is a schematic diagram of an embodiment of a continuous slag removal system **10**. As shown in FIG. **1**, the continuous slag removal system **10** may include a partial oxidation system, such as a gasifier **12**, a slag slurry **14**, a depressurization system **16** (e.g., liquid expansion system, one or more expansion turbines, one or more centrifugal pumps, one or more reciprocating devices, one or more orifice plates, or one or more let down valves), and a controller **18**.

[0018] The partial oxidation system, or gasifier **12**, may further include a reaction chamber **20**, a quench chamber **22**, and a downstream end portion **62**. A protective barrier **24** may enclose the reaction chamber **20**, and may act as a physical barrier, a thermal barrier, a chemical barrier, or any combination thereof. Examples of materials that may be used for the protective barrier **24** include, but are not limited to, refractory materials, non-metallic materials, ceramics, and oxides of chromium, aluminum, silicon, magnesium, iron, titanium, zirconium, and calcium. In addition, the materials used for the protective barrier **24** may be in the form of bricks, a castable refractory material, coatings, a metal wall, or any combination thereof. In general, the reaction chamber **20** may provide a controlled environment for the partial oxidation chemical reaction to take place. A partial oxidation chemical reaction can occur when a fuel or a hydrocarbon is mixed in an exothermic process with oxygen to produce a gaseous product and byproducts. For example, a carbonaceous feedstock **26** may be introduced to the reaction chamber **20** with oxygen **28** to produce an untreated syngas **30** and a molten slag **32**. The carbonaceous feedstock **26** may include materials such as biofuels or fossil fuels, and may be in the form of a solid, a liquid, a gas, a slurry, or any combination thereof. The oxygen **28** introduced to the reaction chamber **20** may be replaced or supplemented with air or oxygen-enriched air. In certain embodiments, an optional slag slurrying agent **34** may also be added to the reaction chamber **20**. The slag slurrying agent **34** may be used to maintain the viscosity of the slag slurry **14** within a suitable range and thus may aid in transporting the slag slurry **14** through the continuous slag removal system **10**. In yet other embodiments, an optional moderator **36** (e.g., water or steam) may also be introduced into the reaction chamber **20**. The chemical reaction within the reaction chamber **20** may be accomplished by subjecting the carbonaceous feedstock **26** to steam and oxygen at elevated gage pressures (e.g., from approximately 2000 to 10,000 kPa, or 3000 to 8500 kPa) and temperatures (e.g., approximately 1100 degrees C. to 1500 degrees C.) depending on the type of gasifier **12** utilized. Under these conditions, and depending upon the composition of the ash in the carbonaceous feedstock **26**, the ash may be in the molten state, which is referred to as molten ash, or molten slag **32**.

[0019] The quench chamber **22** of the partial oxidation system, or gasifier **12**, may receive the untreated syngas **30** and the molten slag **32** as it leaves the reaction chamber **20** through the bottom end **38** (or throat) of the protective barrier **24**. The untreated syngas **30** and the molten slag **32** enter the quench chamber **22** at a high pressure and a high temperature. In general, the quench chamber **22** may be used to reduce the temperature of the untreated syngas **30** and to disengage the molten slag **32** from the untreated syngas **30**, and the quench chamber **22** may be used to quench the molten slag **32** to at least partially solidify the molten slag **32**. In certain embodiments, a quench ring **40** arranged at the bottom end **38** of the protective barrier **24** is configured to provide a quench liquid **42** (e.g. water) to the quench chamber **22**. The quench liquid **42** may be directed through a quench inlet **44** and into the quench ring **40** through a line **46**. In general, the quench liquid **42** may flow through the quench ring **40** and down the inner surface of a dip tube **47** into a quench chamber sump **48**. The controller **18** may control the flow rate of the quench liquid **42** through the quench inlet **44**. For example, the controller **18**

may control the flow rate of the quench liquid **42** to be between approximately 4,000 to 10,000 liters per minute (LPM) (e.g., approximately 1,050 to 2,640 gallons per minute (GPM)), approximately 5,000 to 9,000 LPM (e.g., approximately 1,320 to 2,375 GPM), or approximately 6,000 to 8,000 LPM (e.g., approximately 1,585 to 2,110 GPM).

[0020] The untreated syngas **30** and the molten slag **32** may also flow through the bottom end **38** of the protective barrier **24**, and along the inner surface of the dip tube **47** into the quench chamber sump **48**. As the untreated syngas **30** passes through the pool of quench liquid **42** in the quench chamber sump **48**, the molten slag **32** is solidified and disengaged from the syngas, the syngas is cooled and quenched, and the syngas subsequently exits the quench chamber **22** through a syngas outlet **50**, as illustrated by arrow **52**. Syngas **54** exits through the syngas outlet **50** for further processing in a gas treatment system **56**, where it may be further processed to remove acidic gases, particulates, etc., to form a treated syngas. Solidified slag **58** may accumulate at the bottom of the quench chamber sump **48** and may be continuously removed from the gasifier **12** as the slag slurry **14**. In certain embodiments, a portion of the quench liquid **42** may also be continuously removed from the quench chamber sump **48** for treatment through a quench outlet **60**. For example, particulates, soot, slag, and other matter may be removed from the quench liquid **42** in a black water treatment system, and the treated quench liquid **42** may be returned to the quench chamber sump **48** through the quench inlet **44**. In such embodiments, the removed quench liquid **42** may have properties similar to the slag slurry **14** and thus, may be transported and depressurized using a liquid expansion system separate from or shared with the depressurization system **16** for the slag slurry **14**.

[0021] The slag slurry **14** may have various compositions of solids suspended in the quench liquid **42**, including, but not limited to, fuels (e.g., coals), dry char, catalysts, plastics, chemicals, minerals, and/or other products. The slag slurry **14** entering the downstream end portion **62** of the gasifier **12** may have a high pressure and a high temperature. For example, the gage pressure of the slag slurry **14** may be between approximately 1000 to 10,000 kPa, 2000 to 9000 kPa, or 3000 to 8000 kPa, and the temperature of the slag slurry **14** may be between approximately 150 to 350 degrees C. (e.g., 300 to 660 degrees F.), 200 to 300 degrees C. (e.g., 390 to 570 degrees F.), or 225 to 275 degrees C. (e.g., 435 to 525 degrees F.) or more. In some embodiments, the downstream end portion **62** is narrower than the quench chamber **22**.

[0022] A cooling system **64** controls a flow of a cooling fluid **66** into the downstream end portion **62** via one or more nozzles **68** (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more nozzles). In some embodiments, the cooling system **64** includes a heat exchanger, evaporation system, or refrigerant system to cool the cooling fluid to between approximately 10 to 70 degrees C. The cooling fluid **66** may be at a high gage pressure of between approximately 1000 to 10,000 kPa, 2000 to 9000 kPa, or 3000 to 8000 kPa, and a flow rate of the cooling fluid **66** may be between approximately 1 to 760 LPM (e.g., 0.25 to 200 GPM), 100 to 475 LPM (e.g., 26 to 125 GPM), or 190 to 380 LPM (e.g., 50 to 100 GPM). The flow rate of the cooling fluid **66** may be less than approximately 15 percent (e.g., 3 to 10 percent) of the flow rate of the quench liquid **42** into the quench chamber **22**. For example, the quench liquid **42** flow rate may be approximately 7570 LPM, the cooling fluid **66** flow rate may be approximately 300 LPM, the slag **58** may flow through the downstream end portion **62** of the gasifier **12** with a flow rate of approximately 75 LPM, and the slag slurry **14** (e.g., the cooling fluid **66** and the slag **58**) may flow through the downstream end portion **62** with a flow rate of approximately 375 LPM. The flow rate of the slag slurry **14** may be between approximately 2 to 15% of the flow rate of the quench liquid **42** into the quench chamber **22**. In some embodiments, the temperature of the cooling fluid **66** may be between approximately 10 to 60 degrees C. (e.g., 50 to 140 degrees F.), 20 to 50 degrees C. (e.g., 70 to 125 degrees F.), or 30 to 40 degrees C. (e.g., 85 to 105 degrees F.). The cooling fluid **66** may include, but is not limited to, gray water, boiler feed water, raw makeup water, condensate, other water streams, or any combination thereof.

[0023] The cooling system **64** dispenses the cooling fluid **66** into the downstream end portion **62** to directly cool the slag slurry **14** that will be discharged from the gasifier **12**. One or more streams (e.g., jets) of the cooling fluid **66** interface with slag **58** in the slag slurry **14**, thereby decreasing the temperature of the slag slurry **14**. While the quench liquid **42** cools the syngas **30** and the slag **32** that enters the quench chamber **22** from the reaction chamber **20**, the cooling fluid **66** primarily cools the solidified slag **58** in the slag slurry **14**. The cooling system **64** may be integrated with the downstream end portion **62** of the gasifier **12** and/or coupled directly to the downstream end portion **62** of the gasifier **12**. In some embodiments, the nozzles **68** of the cooling system **64** may be arranged among and/or upstream of one or more slag crushers **70** that receive the slag slurry **14** from the downstream end portion **62**.

[0024] As may be appreciated, certain designs of continuous slag removal systems **10** may include a cooler **72** (e.g., heat exchanger) for the slag slurry **14** and/or may dispense cold water **74** into the slag slurry **14** between the gasifier **12** and a depressurization system **16** (e.g., one or more let down devices). Presently contemplated embodiments of the continuous slag removal system **10** may cool the slag slurry **14** to less than approximately 70 degrees C. (e.g., approximately 160 degrees F.) without the cooler **72** or cold water **74** injection shown in the dashed box **78** downstream of the gasifier **12**. Moreover, the cooling fluid **66** directly cools the solidified slag **58** and the slag slurry **14** in the downstream end portion **62** of the gasifier **12** rather than indirectly, such as when the slag slurry **14** is cooled via a cooler **72** (e.g. heat exchanger) downstream of the gasifier **12**. The removal of the cooler **72** from the continuous slag removal system **10** may reduce the height and/or foot print of the continuous slag removal system **10**. Furthermore, the removal of the cooler **72** from the continuous slag removal system **10** may reduce operational and/or installation costs. The tubes of the cooler **72** may be susceptible to accumulation of slag particulates that may restrict slag slurry flow, and/or the slag slurry may wear or corrode tubes in the cooler **72**.

[0025] The controller **18** may receive signals from various sensors disposed throughout the continuous slag removal system **10**. For example, flow rate sensors **80** measure flow rates of the quench liquid **42**, the cooling fluid **66**, and the slag slurry **14**. One or more pressure sensors **82** and/or temperature sensors **83** may provide information regarding characteristics of the slag slurry **14**, operating conditions within the continuous slag removal system **10**, temperatures of the slag slurry **14**, pressures of the slag slurry **14** at various sites, and so forth. In some embodiments, the controller **18** may receive additional sensor information about the slag slurry **14** as it exits the gasifier **12**, such as, but not limited to, viscosity, particle size, and so forth. Furthermore, the controller **18** may adjust operational conditions of the continuous slag removal system **10** in response to received sensor information, as described in detail below.

[0026] In certain embodiments, one or more slag crushers **70** coupled to a slag crusher driver **84** (e.g., a steam turbine, the depressurization system **16**, a motor, or other source of power) may optionally receive the slag slurry **14** before it is directed through the depressurization system **16**. The one or more slag crushers **70** may crush the solidified slag **58** in the slag slurry **14** in order to attain a desired particle size distribution or a desired average particle size of particles in the slag slurry **14**. The one or more slag crushers **70** may be arranged in one or more stages, and the one or more slag crushers **70** may be arranged in series or in parallel with one another. The one or more slag crushers **70** may include, but are not limited to, rotary screw crushers and toothed rotor slag crushers. Establishing an appropriate particle size distribution may be useful for enabling the slag slurry **14** to flow, for increasing the effectiveness of the cooling system **64**, or for a desired flow through the depressurization system **16**, or any combination thereof. Furthermore, the one or more slag crushers **70** may reduce the average particle size of the solids suspended in the quench liquid **42** and cooling fluid **66** of the slag slurry **14** to an appropriate range.

[0027] In certain embodiments, the one or more slag crushers **70** may reduce the particle size such that the average particle size is between approximately 0.5 to 26 mm (e.g., 0.02 to 1.0 inches), 2 to 8 mm (e.g., 0.08 to 0.31 inches), or 4 to 6 mm (0.16 to 0.24 inches. In one embodiment, the average particle size may be less than 2, 3, 4, 5, or 6 mm. In certain embodiments, a single slag crusher **70** may be sufficient to establish this average particle size, and in other embodiments, two or more slag crushers **70** may function together (e.g., in series and/or in parallel) to establish this average particle size. For example, a first slag crusher may provide a coarse crushing of the slag slurry **14**, while a second slag crusher may provide a finer crushing of the slag slurry **14**. In one embodiment, the controller **18** may control the slag crusher **70** by controlling the slag crusher motor **84**. The controller **18** may adjust the slag crusher motor **84** based on information received from other sensors. In certain embodiments, a flow control valve **86** may be disposed downstream of the slag crusher **70** to adjust the flow rate of the slag slurry **14** flowing to the liquid expansion system **16**. In one embodiment, the controller **18** may receive information about the flow rate of the slag slurry **14** from a flow rate sensor **80**. In response to the information received by the flow sensor **80**, the controller **18** may control the flow rate of the slag slurry **14** by adjusting the flow control valve **86**. In other embodiments, the controller **18** may adjust the flow rate of the slag slurry **14** based on signals from other sensors **82**, **83**.

[0028] The slag slurry **14** may be fed into the depressurization system **16** to decrease the pressure of the slag slurry **14**. In some embodiments, the depressurization system **16** is a turbomachine or expansion machinery, such as, but not limited to, an expansion turbine, a posimetric pump, a rotary screw pump, a modified centrifugal pump, a reciprocating device, a restriction orifice, a let down valve, or any combination thereof. A pressure sensor "P2" **82** may provide information on the pressure of the slag slurry **14** exiting the depressurization system **16**. In some embodiments, the depressurization system **16** (e.g., turbine) may generate power (e.g., drive an electric generator) while depressurizing the slag slurry **14** from the pressure at pressure sensor "P1" 82. For example, the first gage pressure of the slag slurry **14**, as measured by the first pressure sensor "P1" **82**, may be between approximately 1000 to 10,000 kPa, 2000 to 9000 kPa, or 3000 to 8000 kPa, or approximately the high operating pressure of the gasifier **12**. In contrast, the second gage pressure of the slag slurry **14**, as indicated by the second pressure sensor "P2" **82**, may be between atmospheric pressure (0 kPa) to 100 kPa, 20 to 80 kPa, or 40 to 60 kPa. In certain embodiments, the second pressure is approximately equal to atmospheric pressure. After exiting the depressurization system **16**, the slag slurry **14** may travel further downstream to a slag processing system **88**, such as for dewatering of the slag slurry **14**, before the slag slurry **14** is disposed of.

[0029] FIG. **2** illustrates an embodiment of the downstream end portion **62** of the gasifier **12** and an embodiment of the cooling system **64**. The quenched and solidified slag **58** may settle from the quench chamber **22** into the downstream end portion **62**. Within the downstream end portion **62**, the solidified slag **58** forms the slag slurry **14** with the quench liquid **42** and the cooling fluid **66**. The cooling system **64** may have one or more nozzle sets **100** (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or more) to dispense the cooling fluid **66** (e.g., water) into the downstream end portion **62**, and each nozzle set **100** may have one or more nozzles **68** (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or more). For example, a first nozzle set **102** may have 2 nozzles **68**, and a second nozzle set **104** and a third nozzle set **106** may each have 4 nozzles **68**.

[0030] FIG. **3** illustrates a cross-sectional view of an embodiment of the first nozzle set **102**, taken along line **3-3** of FIG. **2**. The nozzles **68** of each nozzle set **100** may extend through a wall **108** of the downstream end portion **62** of the gasifier **12**. Each of the nozzles **68** may be oriented toward a center **110** of the downstream end portion **62**, in a first tangential direction **112**, or a second tangential direction **114**, or any combination thereof. For example, a first nozzle **116** may be oriented toward the center **110** and a second nozzle **118** may be oriented in the first tangential direction **112**. In some embodiments, one or more nozzles **68** of a nozzle set **100** may extend through the wall **108** to the center **110** and be oriented towards the wall **108** in a radial direction **120** from the center **110**, to induce counter-clockwise swirl, and a third nozzle **116** may be oriented in the second tangential direction **114** to induce clockwise swirl. Each of the one or more nozzles **68** may dispense the cooling fluid **66** in a jet or stream that penetrate the flow of the slag slurry **14**, thereby enabling the cooling fluid **66** to directly interface and contact the slag **58** in the slag slurry **14**. In some embodiments, one or more of the nozzles **68** may dispense the cooling fluid **66** into the slag slurry **14** as a stream (e.g., jet) a sheet (e.g., vertical sheet, horizontal sheet, oblique sheet), or a cone, or any combination thereof.

[0031] The one or more nozzle sets **100** depicted in FIGS. **2** and **3** may have various arrangements of the one or more nozzles **68**. In some embodiments, arrangements of the nozzles **68** in each nozzle set **100** may be rotationally symmetric about the center **110**, thereby enabling the cooling system **64** to cool the slag slurry **14** to a substantially uniform temperature (e.g., less than approximately 50 to 95 degrees C., less than approximately 60 to 80 degrees C., or less than approximately 70 degrees C.). For example, the second nozzle **118** may be spaced by approximately 180° from the first nozzle **116**, as illustrated in FIG. **3**. As may be appreciated, the term "approximately" as used herein to describe arrangement of the nozzles **68** may be within 10° or less. Other arrangements of the one or more nozzle sets **100** may include, but are not limited to, an arrangement with nozzles **68** spaced from one another by approximately 90° (e.g., the first nozzle **116**, a third nozzle **120**, the second nozzle **118**, a fourth nozzle **122**) or by approximately 60° (e.g., the fourth nozzle **122**, a fifth nozzle **124**, and a sixth nozzle **126**), as illustrated in FIG. **3**. In some embodiments, multiple nozzle sets **100** may be arranged on the wall **108** such that the nozzles **68** are circumferentially offset about the center **110** to enable the nozzles **68** to dispense the cooling fluid **66** to cool different portions of the slag slurry **14**. For example, the first nozzle set **102** may have four nozzles **68** spaced by approximately 90° from each other starting at a first point **128**, and the second set **104** may have four nozzles **68** spaced by approximately 90° from each other starting at a second point **130**.

[0032] Returning to FIG. **2**, each nozzle set **100** dispenses (e.g., injects) the cooling fluid **66** (e.g., water) into the downstream end portion **62**. The cooling fluid **66** may be dispensed at a relatively high gage pressure (e.g., between approximately 1000 to 10,000 kPa) that is greater than or approximately equal (e.g., within 10 percent or less) to the gage pressure of the slag slurry **14**, thereby enabling the cooling fluid **66** to readily flow into the slag slurry **14**. In some embodiments, substantially all (e.g., greater than 75 percent) of the cooling fluid **66** may cool the slag slurry **14** and flow through an exit **132** of the downstream end portion **62** rather than through the syngas outlet **50** or the quench liquid outlet **60**. Accordingly, the cooling fluid **66** primarily cools the slag slurry **14** downstream of the quench chamber **22**.

[0033] In some embodiments, the downstream end portion **62** may include one or more slag crushers **70** to establish a desired average particle size. As discussed above, a first slag crusher **134** may provide a coarse crushing of the slag slurry **14**, while a second slag crusher **136** may provide a finer crushing of the slag slurry **14**. Each slag crusher **70** may include one or more elements **138** for breaking up the solidified slag **58** in the slag slurry **14**, although other types of slag crushers may be used alone or in combination with slag crushers **70** having elements **138**. Additionally, or in the alternative to one or more slag crushers **70** in the downstream end portion **62**, some embodiments may include one or more slag crushers **70** downstream of the exit **132**.

[0034] The one or more nozzle sets **100** may be arranged among the one or more slag crushers **70** of the downstream end portion **62**. In some embodiments, a nozzle set **100** (e.g., the second nozzle set **104**) is arranged between the first and the second slag crushers **134**, **136**. Additionally, or in the alternative, a nozzle set **100** (e.g., the first nozzle set **102**) may be arranged upstream of the slag crusher **70** and/or a nozzle set **100** (e.g., the third nozzle set **106**) may be arranged downstream of the slag crusher **70**. The cooling system **64** may include one or more flow control valves and/or manifolds to control the distribution of the cooling fluid to the one or more nozzle sets **100**. The cooling system **64** may differentially control the flow of the cooling fluid **66** to each of the nozzle sets **100**. For example, the cooling system **64** may direct more cooling fluid **66** to the second or third nozzle sets **104**, **106** while directing less cooling fluid **66** to the first nozzle set **102**. In some embodiments, the cooling system **64** may differentially control the flow of the cooling fluid **66** to each nozzle **68** of a respective nozzle set **100**. For example, the cooling system **64** may direct more cooling fluid **66** to a nozzle **68** proximate to a warm component of the continuous slag removal system **10** and less cooling fluid **66** to a nozzle **68** proximate to a cooler external ambient environment.

[0035] In some embodiments, the depressurization system **16** may include one or more let down devices including, but not limited to, one or more orifice plates **140**, one or more let down valves **142**, one or more expansion turbines **144**, or one or more reverse-acting centrifugal pumps, or any combination thereof. The one or more let down devices may depressurize the slag slurry **14** based at least in part on the flow rate of the slag slurry **14** and/or the particle size of the solidified slag **58** within the slag slurry **14**. For example, the one or more orifice plates **140** and/or the one or more let down valves **142** may depressurize the slag slurry **14** a greater amount when the slag slurry **14** flows at a first flow rate (e.g., approximately 380 LPM) than when the slag slurry **14** flows at a decreased second flow rate (e.g., approximately 300 LPM). Accordingly, the controller **18** may control the flow rate of the slag slurry **14** to control the depressurization of the slag slurry **14**. In some embodiments, the controller **18** may control the flow rate of the slag slurry **14** via controlling the flow rate of the cooling fluid **66** from the cooling system **64**. For example, increasing the cooling fluid **66** flow rate may increase the flow rate of the slag slurry **14** and increase the pressure drop across the depressurization system **16**. Conversely, decreasing the cooling fluid **66** flow rate may decrease the flow rate of the slag slurry **14** and decrease the pressure drop across the depressurization system **16**. Controlling the flow rate of the cooling fluid **66** may enable the controller **18** to exercise a fine control of the flow rate of the slag slurry **14** to satisfy any minimum flow specifications of the depressurization system **16** relative to control of the flow rate of the quench liquid **42**. For example, adjusting the flow rate of the cooling fluid **66** by about 10 percent (e.g., from 380 LPM to **340** LPM) may affect the flow rate of the slag slurry **14** less than adjusting the flow rate of the quench liquid **42** by about 10 percent (e.g., from 7570 LPM to 6800 LPM). Additionally, or in the alternative, the controller **18** may control the flow rate of the slag slurry **14** directly via controlling a flow control valve **86**.

[0036] Adjusting the flow rate of the slag slurry **14** via controlling the flow rate of the cooling fluid **66** from the cooling system **64** may enable the cooling system **64** to accommodate a flow rate specification of the depressurization system **16** without adding fluid between the downstream end portion **62** and the depressurization system **16**. In some embodiments, the controller **18** may control the flow rate of the slag slurry **14** and/or the flow rate of the cooling fluid **66** based at least in part on feedback from a pressure sensor **82** downstream of the depressurization system **16**. The controller **18** may also control the flow rate of the slag slurry **14** and/or the flow rate of the cooling fluid **66** based at least in part on a temperature of the slag slurry **14**. For example, the controller **18** may control the flow rate of the slag slurry **14** and/or the cooling fluid **66** to cool the slag slurry to less than approximately 50 to 95 degrees C., less than approximately 60 to 80 degrees C., or less than approximately 70 degrees C. As may be appreciated, a processor **146** of the controller **18** may execute instructions (e.g., code) stored in a memory **148** of the controller **18** to control the cooling fluid **66** flow rate and/or the slag slurry **14** flow rate. Accordingly, the cooling system **64** coupled to the downstream end portion **62** may reduce the complexity of the flow path of the slag slurry **14** from the gasifier **12** to the depressurization system **16**. Thus, the cooling fluid **66** may be utilized to cool the slag slurry **14** and to control the flow rate of the slag slurry **14** to sufficiently depressurize the slag slurry **14** without vapor flash.

[0037] FIG. **4** is a flowchart illustrating a process **180** for continuously handling the slag slurry **14**. In some embodiments, the process **180** begins when carbonaceous fuel reacts (block **182**) in the gasifier **12**. As described above, the carbonaceous fuel may react with an oxidant and optionally additional water. Upon reaction within the gasifier **12**, the continuous slag removal system **10** adds (block **184**) a quench liquid to a quench chamber **22** in the gasifier **12** at a first flow rate, and quenches (block **186**) the reacted products, such as a gas product and a slag byproduct. The gasifier **12** then separates (block **188**) the gas from the slag, and conveys (block **190**) the gas to the gas treatment system. As described above, the continuous slag removal system **10** adds (block **192**) the cooling fluid to the downstream end portion **62** of the gasifier **12** at a second flow rate, thereby cooling (block **194**) the slag and forming (block **196**) the slag slurry. The slag slurry may be cooled to less than approximately 50 to 95 degrees C., less than approximately 60 to 80 degrees C., or less than approximately 70 degrees C. In some embodiments, one or more slag crushers **70** may crush the slag to form the slag slurry, which may include the slag, a first portion of the cooling fluid, and a second portion of the added quench liquid. In some embodiments, the second flow rate of the cooling fluid may be between approximately 2 to 15 percent, approximately 3 to 10 percent, or approximately 3 to 7 percent of the first flow rate of the quench liquid. The continuous slag removal system **10** conveys (block **198**) the slag slurry at a third flow rate to a depressurization system **16** that depressurizes (block **200**) the slag slurry. The third flow rate is based at least in part on the second flow rate. The continuous slag removal system **10** may control the third flow rate to depressurize (block **200**) the slag slurry to a desired pressure, such as approximately atmospheric pressure.

[0038] Technical effects of the invention include enabling a continuous slag removal system without a cooler and/or water added between a downstream end portion of a gasifier and a depressurization system. A cooling system dispenses a high gage pressure cooling fluid to cool the slag slurry in the downstream end portion of the gasifier to less than approximately 50 to 95 degrees C. (e.g., 120 to 200 degrees F.), less than approximately 60 to 80 degrees C. (e.g., 140 to 175 degrees F.), or less than approximately 70 degrees C. (e.g., 160 degrees F.), thereby reducing the likelihood of vapor flash in the depressurization system. In addition to cooling the slag slurry, the cooling fluid may be used to control the flow rate of the slag slurry to the depressurization system. The pressure drop across the depressurization system may be based at least in part on the flow rate of the slag slurry through the depressurization system. Accordingly, controlling the slag slurry flow rate via control of the cooling fluid flow rate may control the pressure drop across the depressurization system.

[0039] 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:

a quench chamber configured to continuously receive a mixture of a gas and slag, wherein the quench chamber comprises a quench sump configured to continuously separate the gas from the slag in the mixture via a quench liquid; and

a downstream end portion coupled to the quench chamber, wherein the downstream end portion is configured to continuously convey a slag slurry to a depressurization system, the downstream end portion comprises a cooling system configured to directly cool the slag slurry with a cooling fluid, and the slag slurry comprises the separated slag and at least a portion of the cooling fluid.

2. The system of claim **1**, comprising one or more slag crushers configured to receive the slag slurry.

3. The system of claim **2**, wherein the cooling system is disposed at least partially between a first slag crusher of the one or more slag crushers and a second slag crusher of the one or more slag crushers.

4. The system of claim **2**, wherein the cooling system is disposed at least partially upstream of the one or more slag crushers.

5. The system of claim **1**, comprising a slag crusher coupled to the downstream end portion.

6. The system of claim **1**, comprising a reactor coupled to the quench chamber, wherein the reactor is configured to react a carbonaceous feedstock to generate the gas and the slag.

7. The system of claim **1**, wherein the cooling system comprises one or more nozzles configured to dispense the cooling fluid directly into the slag slurry.

8. The system of claim **1**, wherein the cooling system comprises a plurality of nozzle sets configured to dispense the cooling fluid, wherein each nozzle set comprises one or more nozzles, and each of the one or more nozzles is configured to dispense the cooling fluid at a different angle than another of the one or more nozzles of the respective nozzle set, at a different axial position than another of the one or more nozzles of the respective nozzle set, at a different circumferential position than another of the one or more nozzles of the respective nozzle set, or any combination thereof.

9. The system of claim **1**, wherein the cooling system is configured to cool the slag to less than approximately 70 degrees C.

10. A system comprising:

a gasifier configured to react a carbonaceous feedstock into a mixture of a gas and slag, wherein the gasifier comprises:

a quench sump configured to continuously separate the gas from the slag in the mixture via a quench liquid, wherein the quench liquid is configured to flow through the quench sump at a first flow rate; and

a downstream end portion of the gasifier comprises a cooling system, wherein the downstream end portion is configured to continuously convey a slag slurry to a depressurization system at a third flow rate approximately 15 percent or less of the first flow rate, the downstream end portion is configured to add a cooling fluid at a second flow rate to cool the slag slurry, and the slag slurry comprises the slag and the cooling fluid; and

a controller configured to control the second flow rate.

11. The system of claim **10**, comprising one or more slag crushers configured to continuously receive the slag slurry.

12. The system of claim **10**, comprising the depressurization system coupled to the downstream end portion, wherein the depressurization system comprises one or more orifice plates, one or more let down valves, one or more expansion turbines, one or more centrifugal pumps, or any combination thereof.

13. The system of claim **12**, wherein the controller is configured to control the second flow rate based at least in part on a desired flow rate of the depressurization system.

14. The system of claim **10**, wherein the cooling system is configured to directly cool the slag slurry to reduce vaporization of the slag slurry upon depressurization in the depressurization system.

15. The system of claim **10**, comprising a plurality of sensors configured to provide feedback to the controller, wherein the feedback comprises temperature data, pressure data, flow data, or viscosity data, or any combination thereof.

16. The system of claim **10**, wherein the slag comprises less than approximately 5 percent of the quench liquid.

17. A method, comprising:

separating slag from a gas, wherein a temperature of the slag is greater than approximately 175 degrees C.;

dispensing a cooling fluid into a downstream end portion of a gasifier, wherein the cooling fluid is configured to decrease the temperature of the slag to less than approximately 70 degrees C.;

forming a cooled slag slurry from the slag and the cooling fluid; and

conveying the cooled slag slurry substantially continuously through an exit of the downstream end portion.

18. The method of claim **17**, wherein forming the cooled slag slurry comprises crushing the slag into a plurality of particles with one or more slag crushers.

19. The method of claim **18**, wherein the cooling fluid is dispensed upstream, downstream, or between the one or more slag crushers.

20. The method of claim **18**, wherein separating the slag from the gas comprises supplying a quench liquid at a first flow rate, wherein the cooling fluid is dispensed at a second flow rate, and the second flow rate is less than approximately 15 percent of the first flow rate.

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