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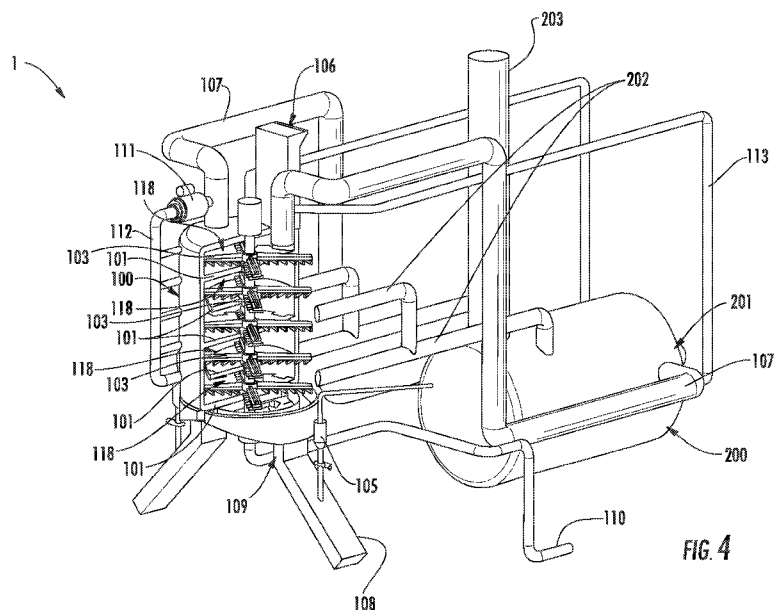
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(54) **Title:** MULTI-HEARTH ROASTERS FOR USE IN METAL RECYCLING PROCESSES



MULTI-HEARTH ROASTERS FOR USE IN METAL RECYCLING PROCESSESCross Reference to Related Application

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 62/220,591, filed on September 18, 2015 and entitled “Multi-Hearth Roasters for Use in Metal Recycling Processes,” which is hereby incorporated in its entirety by this reference.

Field of the Invention

[0002] The present disclosure generally relates to roasters for use in metal recycling processes. More specifically, the present disclosure relates to the use of multi-hearth roasters to decontaminate scrap metal in recycling processes.

Background

[0003] Traditionally, rotary kilns have been used in metal recycling operations to treat metal scrap that has been collected and shredded in preparation for recycling. Rotary kilns or roasters are used to dry the shredded scrap material and to remove volatile organic compounds (VOCs), organics, paint, plastics, or other contaminants that are not easily removed before melting. Drying and decontaminating the shredded scrap material is a vital step prior to melt down and final processing in the recycling process. More specifically, proper removal of the VOCs, carbon, and paint on the scrap material is critical to improving recovery in the recycling process.

[0004] However, rotary kilns pose a number of challenges for metal recycling operations. For example, rotary kilns are difficult or impossible to seal effectively. As a result, accurate controls of the atmospheric composition of rotary kilns cannot be accurately controlled. Controlled pyrolysis of the VOCs requires a low oxygen level to control the combustion of the organic material. At five percent organic content in a scrap mix, there is enough energy

to melt aluminum. An air leak at twenty-one percent oxygen levels can cause a complete melt down of the rotary kiln. Rotary kilns also roast shredded scrap material at a single temperature selected to be high enough to vaporize, ignite, or decompose any expected organic compounds or contaminants that might be present in the shredded scrap material. The lack of atmospheric composition controls and a single roasting temperature can cause uncontrolled ignition of combustible organic compounds leading to a risk of fire or explosion. Due to the potential fire and explosion risks associated with operating a rotary kiln, recyclers are often limited to scrap material that contains no more than five percent organics or contaminants by weight. Furthermore, rotary kilns are typically large, horizontal cylinders which take up large amounts of space in processing plants and can be inefficient and expensive to operate.

Summary

[0005] Aspects of the present disclosure relate to the use of multi-hearth kilns or roasters to remove contaminants including volatile organic compounds (VOCs), paints, plastic, and other organic materials from scrap metal, such as aluminum, for recycling. The disclosed multi-hearth kilns or roasters have a number of individual heating zones defined by hearths that are separate from one another. Each zone or hearth of the multi-hearth roaster may be held at a different temperature and can be designed or operated to allow for control of the atmospheric composition and pressure within that particular zone. For example, different zones of the multi-hearth roaster may have inert, oxidizing, or reducing atmospheres to affect different outcomes within that zone. With multiple zones that can be independently controlled, the disclosed multi-hearth roasters may gradually remove VOCs, paint, plastic, or other organic compounds from scrap metal in stages, allowing the multi-hearth roaster to

accommodate scrap that contains a wide variety of contaminants at much higher levels than traditional roasting equipment.

[0006] Multi-hearth roasters also offer several opportunities to improve efficiency of the removal of contaminants and the overall recycling process. For example, because individual zones or hearths of the multi-hearth roaster may be sealed off from the outside environment and one another, it is possible to collect and transfer the gases from one zone to another. Transferring gases from a relatively hotter zone to a relatively cooler zone allows the cooler zone to take what would otherwise be waste gas from a hotter zone and use it for heating purposes with less additional heat input from an incinerator or burner. In certain applications, gases containing combustible compounds from the multi-hearth roaster may be collected and routed to an incinerator or burner to supplement traditional fuel sources. In this way, the contaminants of the scrap metal may be used to help fuel the roasting process. In addition, routing waste gases from the multi-hearth roaster to an incinerator or burner allows the processing of potentially harmful byproducts, such as phosgene or dioxins, in a high temperature environment to burn or otherwise neutralize their harmful effects.

[0007] Multi-hearth roasters may be combined with control systems to further enhance efficiency and safety. Sensors for temperature, atmospheric composition, pressure, and/or other process parameters may be used to measure the particular conditions of an individual hearth. Based on these measurements or other known factors, like the type of scrap material, target process conditions, or mass flow rate of scrap material, operators or controllers may make adjustments to temperature, scrap material throughput, gas recirculation, incinerator or burner output, or other controlled quantities.

Brief Description of the Drawings

[0008] Illustrative embodiments of the present disclosure are described in detail below with reference to the following drawing figures:

[0009] Figure 1 is a schematic side sectional view of a multi-hearth roaster.

[0010] Figure 2 is a schematic side sectional view of a heating zone of the multi-hearth roaster of Figure 1.

[0011] Figure 3 is a schematic side sectional view of the multi-hearth roaster of Figure 1 in conjunction with a melt furnace.

[0012] Figure 4 is a perspective view of a multi-hearth roaster with an external incinerator.

[0013] Figure 5 is a schematic side sectional view of the multi-hearth roaster of Figure 4.

[0014] Figure 6A is a schematic view of a multi-hearth roaster with an external incinerator and a gas control manifold, according to one example.

[0015] Figure 6B is a detailed schematic view of a portion of the gas control manifold of Figure 6A.

Detailed Description

[0016] The subject matter of embodiments of the present invention is described here with specificity to meet statutory requirements, but this description is not necessarily intended to limit the scope of the claims. The claimed subject matter may be embodied in other ways, may include different elements or steps, and may be used in conjunction with other existing or future technologies. This description should not be interpreted as implying any particular order or arrangement among or between various steps or elements except when the order of individual steps or arrangement of elements is explicitly described.

[0017] Certain aspects and features of the present disclosure relate to the use of a multi-hearth roaster or kiln to decontaminate and/or remove volatile organic compounds (VOCs),

paints, coatings, plastics, and other organics from scrap metal, such as aluminum, prior to melt down for recycling. Use of the disclosed multi-hearth roasters allows for a wider variety of scrap materials with higher concentrations of organics and other contaminants to be processed more efficiently than traditional rotary kilns.

[0018] In certain cases, the multi-hearth roaster has a number of hearths that define heating zones which may be held at different temperatures and pressures, and maintain inert, oxidizing, or reducing atmospheric compositions. Because each heating zone of the multi-hearth roaster can have different processing conditions, it is possible to gradually remove and vaporize any contaminants that may be present in the scrap materials. For example, scrap material may enter the multi-hearth roaster in the top, coolest heating zone and progressively move to successively lower heating zones which are held at higher temperatures. Since different contaminants in the metal scrap vaporize, ignite, or decompose at different temperatures, some will be reactive in relatively cooler heating zones, while others will not become reactive until later, relatively hotter heating zones. For example and without limitation, scrap material that may enter the multi-hearth roaster may include a combination of plastisol, acrylic, polyester, epoxy urea without pigment, epoxy urea with pigment, vinyl organsol, silicone polyester, and various other materials. In this example, plastisol may decoat after being exposed to a temperature of about 450 degrees Celsius for about 1 minute, acrylic may decoat after being exposed to a temperature of about 450 degrees Celsius for about 4 minutes, polyester may decoat after being exposed to a temperature of about 475 degrees Celsius for about 5 minutes, epoxy urea without pigment may decoat after being exposed to a temperature of about 450 degrees Celsius for about 12 minutes, epoxy urea with pigment may decoat after being exposed to a temperature of about 500 degrees Celsius for about 8 minutes, vinyl organsol may decoat after being exposed to a temperature of about 500

degrees Celsius for about 12 minutes, and silicone polyester may decoat after being exposed to a temperature of about 550 degrees Celsius for about 12 minutes.

[0019] In some examples, because various contaminants have different flash points, the dwell time in each hearth, or the amount of time that the scrap material spends in each hearth, may be adjusted depending on an amount of the contaminant present at that hearth's temperature. In some examples, each hearth can be set to a certain temperature range to aid in removal of the respective contaminants. In certain cases, the temperature of each heating zone may be controlled between about 350 degrees Celsius and about 550 degrees Celsius, depending on the level of the heating zone. In some examples, each hearth may be individually controlled to a higher or lower temperature relative to adjacent hearths based on the reactions observed. For example and without limitation, if the scrap material includes low VOC's, the hearths may all run at about the same temperature, such as about 550 degrees Celsius. As another non-limiting example, for a scrap material with high VOC's, some hearths may operate at a relatively lower temperature, such as about 450 degrees Celsius, and some hearths may operate at a relatively higher temperature, such as about 550 degrees Celsius. The staged vaporization and reaction of compounds ensures that not all of the contaminants are removed from the scrap material at once. As a result, the multi-hearth roaster will gradually release volatile compounds in a controlled manner, reducing the risk of uncontrolled ignition of combustible gases inside the multi-hearth roaster. Scrap metal with concentrations of organics, VOCs, paints, and plastics in excess of ten percent by weight can be safely processed with greatly reduced risk of uncontrolled burn, fire, or explosions.

[0020] In certain cases, a multi-hearth roaster may be particularly suited to the treatment of aluminum scrap, which may be characterized by high levels of organics and other contaminants, particularly in the case of used beverage cans. In some examples, volatiles in scrap material may be vaporized or removed through direct exposure to flames or through

indirect exposure to flames (as shown in Figure 6A) that supply combustion gases with a controlled amount of oxygen, for example 3% oxygen. In certain cases, the volatiles can then be transported to an incinerator to be burned, as illustrated in Figure 6A and as discussed in more detail. In some examples, some of the hot gases exiting the incinerator may be routed back to the multi-hearth roaster.

[0021] In some cases, the multi-hearth roaster may also increase efficiency and reduce space requirements in a recycling facility. Unlike traditional kilns or roasters, multi-hearth roasters may be oriented vertically and require far less floor space than other kiln or roaster designs. Multi-hearth roasters may also increase process efficiency by recycling gases both between heating zones of the respective hearths, and by collecting and burning volatile or combustible gases that are released by the scrap metal during heating. For example, the multi-hearth roaster may include zone-to-zone gas recirculation to direct gases between heating zones of different hearths. Gases directed from a hotter heating zone of one hearth to a cooler heating zone of another hearth may be used to help heat the cooler heating zone without the need for burning additional fuel. Similarly, zone-to-zone gas recirculation may direct gases from a cooler heating zone of one hearth to a hotter heating zone of another hearth to reduce the temperature of a hotter heating zone to maintain a desired temperature range. Gases may also be transferred from a first heating zone of one hearth to a second heating zone of another hearth so that combustible gases may be consumed in the burners of the second heating zone. This gas transfer may be particularly advantageous when the second heating zone can more fully utilize the combustible gases for heating that may not be needed or available in the first heating zone. In some examples, the gas transfer between hearths may lower the oxygen content in the second hearth due to reactions occurring in the first hearth and may utilize the heat in the second hearth.

[0022] Gases also may be collected from one or more heating zones of the multi-hearth roaster and directed to an external heat source where they may be burned or otherwise used as fuel. As one non-limiting example, in Figure 6A, the gases are routed from the multi-hearth roaster to the incinerator to be used as fuel. Burning recirculated gases can contribute to process heating requirements and reduce the amount of fuel required to maintain multi-hearth roaster temperatures within range. The use of an external heat source, such as the incinerator or a remote furnace, may also allow harmful or poisonous products of the multi-hearth roaster to be burned at a temperature higher than the process temperature in the heating zones of the multi-hearth roaster. For example and without limitation, phosgene or dioxins, which may not decompose or break down at the temperatures within the heating zones of the multi-hearth roaster, may be directed towards an external heat source to be burned and/or exposed to temperatures in the external heat source which are high enough to decompose, burn, or otherwise break down harmful or toxic chemicals into benign products.

[0023] In some cases, multi-hearth roaster gases may be directed to integrated heat sources within the heating zones themselves to be burned within the multi-hearth roaster and provide many, if not all, of the aforementioned benefits. The heat sources may be integrated burners or other combustion devices; however, other heat sources, such as electric heaters, may be used. As described in greater detail below, the heat sources may be separate from the multi-hearth roaster in various other examples. Heat exchangers and/or sterling cycles may be used to cool the effluent gases, and energy may be generated through the combustion of VOCs. Heat may be removed via a heat exchanger or directly converted into mechanical energy (e.g., via a sterling cycle, Rankine cycle, or other heat engine), electrical energy (e.g., thermoelectric elements), or chemical energy (e.g., an endothermic chemical reaction) for use outside the process.

[0024] In addition to removing contamination from scrap material, the multi-hearth roaster is easily adaptable to drying scrap material prior to recycling processing. The multi-hearth roaster may, with minimal changeover of equipment or process parameters, be used to dry scrap material which is already decontaminated, or dry and decontaminate scrap material in a single processing step.

[0025] Figure 1 is a schematic sectional view of an example of a multi-hearth roaster 100. The multi-hearth roaster 100 includes a plurality of hearths 101, and each hearth 101 defines a heating zone 118. Scrap metal, which may be aluminum or aluminum alloys, enters the inlet 106 positioned above the upper-most heating zone 118. Burners 201 can provide heat to the heating zones 118. The burners 201 can be controlled to help moderate the temperature of the heating zone 118 of each hearth 101 as needed.

[0026] In some examples, the burners 201 can be integrated in the hearths 101 such that there may be exposed flames within each hearth 101. In these examples, the burner 201 may provide both convection and radiation heat transfer. Because radiation from the flame can be uncontrollable, in other examples, such as the example illustrated in Figure 6A, the burners 201 may be separate from the hearths 101 such that the exposed flames are not within each hearth 101. In these examples, the exposed flames of the burners 201 are separate from the multi-hearth roaster 100 and the hot gases may indirectly enter the multi-hearth roaster 100 via a combustion box. In some examples, the combustion boxes may reduce uncontrolled radiation heat transfer in the hearths 101 and on the scrap material. In other examples, the combustion boxes may provide only convection heat transfer on the scrap material, which may provide more uniform heat transfer. In addition, control sensors utilized with the multi-hearth roaster 100, such as temperature control sensors, pressure control sensors, flow control sensors, and various other types of control sensors, may be more accurate because the heat transfer is more controlled.

[0027] In some cases, each hearth 101 may have its own burner 201. In other examples, for example as illustrated in Figure 6A, a single burner 201 may provide heat to multiple hearths 101. In these examples, to control the temperature at each hearth 101, colder gases may be mixed with the hot gas from the burner 201. The colder gases may be introduced via various valves, as illustrated in Figure 6B.

[0028] In some examples, a series of rabble arms 103 agitate and circulate scrap metal while it is heated in the heating zone 118. The rabble arms 103 are designed to mix and move the scrap metal such that it gradually migrates towards a hearth passage 102 where it may be transferred from one heating zone 118 to the next lowest heating zone 118. As depicted in Figure 1, the hearth passages 102 may be arranged such that they are at or near the center of one hearth 101 near the rabble arm shaft 117 while adjacent hearths 101 may have hearth passages 102 at the perimeter of the hearth 101. However, the hearth passages 102 may be arranged in any configuration so as to achieve a desired dwell time within a heating zone 118, mass flow rate between heating zones 118, or any other process parameter as desired or required by a particular application. For example, the hearth passages 102 may be located at 180 degrees to the hearth passages 102 of the adjacent hearths 101. The placement of the hearth passages 102 in successive hearths 101 can be used to tailor mass flow between successive hearths 101 and to prevent excess intermingling of gases or atmospheric constituents between heating zones 118. In certain cases, the hearth passages 102 may include doors or other moveable obstructions (not shown) to allow scrap metal to pass through the hearth passages 102 only when the door or moveable obstruction is positioned such that the hearth passages 102 are open.

[0029] In some examples, dimensions of each hearth 101, such as a hearth diameter, can optionally be varied to control bed depths of the scrap material in each hearth 101 and thereby dwell time in each hearth 101. For example and without limitation, a physical

diameter of the hearth 101 may be varied. In other examples, the location of the hearth passages 102 can be moved inwards or outwards to reduce or increase the travel distance of the scrap material in each hearth 101. In some of these examples, an inner wall may be utilized within the hearths 101 to aid in guiding the scrap material towards the hearth passages 102 and prevent the material from traveling past the hearth passages 102.

[0030] After the scrap metal has passed through each successive heating zone 118, the scrap may be agitated by the rabble arms 103 towards a discharge chute 108 where decontaminated scrap material can be transferred to holding bins, a conveyor, other treatment processes, or directly into a melt furnace. Referring to Figure 1, the rabble arms 103 may be mounted to a rabble arm shaft 117, which may be rotated by a drive motor 114 to turn the rabble arms 103 and agitate the scrap metal in the respective heating zones 118. The rate of rotation of the rabble arm shaft 117, and subsequently the rabble arms 103, can be varied to increase or decrease the amount of time that scrap material spends in a particular heating zone 118. For example and without limitation, increasing the rate of rotation of the rabble arm shaft 117 can move scrap material more quickly through individual heating zones 118 toward hearth passages 102, and the multi-hearth roaster 100 as a whole, to decrease the dwell time of the scrap material in the decontamination process. Conversely, slowing the rate of rotation will increase the dwell time of the scrap material in the multi-hearth roaster 100.

[0031] In some examples, the single motor 114 may rotate the rabble arm shaft 117 and thereby rotate the rabble arms 103. In other examples, it may be desirable to change or vary the rotation of rabble arms 103 in one hearth 101 compared to another hearth 101. In these examples, the multi-hearth roaster 100 may optionally be divided into several sections, and each section may include a separate motor to rotate the rabbles arms 103 within that section. In this manner, the rate of rotation of rabble arms 103 in one section may be the same or different from the rate of rotation of rabble arms 103 in another section. In these examples,

the sections may be connected via a transfer tube and gas control to control atmosphere and scrap material flow.

[0032] In other examples, the design of the rabble arms 103 within each section may optionally be varied to move the scrap at different rates depending on the hearth 101. For example and without limitation, the pitch design and/or rake design of the rabble arm 103 can be varied. The design of the rabble arms 103 accordingly can be varied to vary the bed depth of scrap material within each hearth 101.

[0033] Increasing or decreasing the in-feed rate of scrap material through the inlet feed 106 will also tend to increase or decrease the dwell time of scrap material as it moves through the heating zones 118 and multi-hearth roaster 100. For example, increasing the in-feed rate of scrap material through the inlet feed 106 may increase the depth of scrap material on a hearth 101. In certain cases, it may be desirable to change the depth of scrap material on a hearth 101 from approximately one to two inches to approximately four to five inches, or vice versa. Varying the depth of scrap on any particular hearth 101 may allow for altering the dwell time and/or process rate while maintaining a constant rotational speed of the rabble arms 103. Adjustments to the dwell time of the scrap material in the multi-hearth roaster 100 for decontamination may be made based on the level of contaminants that must be removed from the scrap, matching the mass flow rate of the multi-hearth roaster 100 to the mass flow rate of other steps in the recycling process, multi-hearth roaster 100 and heating zone 118 temperature, furnace requirements, or other considerations of process efficiency.

[0034] Seals 115 may be used at the upper and lower ends of the rabble arm shaft 117 to maintain a sealed environment for the multi-hearth roaster 100. In certain cases, particularly where different atmospheric compositions may be required among the heating zones 118, additional sealing between the hearths 101 and the rabble arm shaft 117 may improve sealing between heating zones 118. Effective sealing of the heating zones 118 and multi-hearth

roaster 100 as a whole allows for control over the atmospheric composition of individual heating zones 118 and the multi-hearth roaster 100 as a whole. For example, the atmosphere in one, multiple, or all heating zones 118 may be inert, reducing, or oxidizing. In other examples, the heating zones 118 can be various other chemically reactive environments.

[0035] In certain cases, it may be particularly important to control the amount of oxygen present in any particular heating zone 118 or the multi-hearth roaster 100 overall. Remote burners, which may also pre-heat air entering the multi-hearth roaster 100, can control oxygen concentrations in the heating zones 118 by consuming oxygen in combustion before it enters the multi-hearth roaster 100 or heating zones 118. In some cases, atmospheric concentrations of one-tenth of one percent oxygen or less may be achievable. In some examples, a 10:1 ratio of air to gas may be achieved. The atmospheric composition of the multi-hearth roaster 100 and individual heating zones 118 can be tailored for specific scrap materials through insertion or injection of gases like nitrogen and argon, or oxidizers. Seals 115 and additional seals between heating zones 118 allow for enhanced control and increased flexibility in scrap material that may be processed in the multi-hearth roaster 100.

[0036] In other examples, the rabble arm shaft 117 may optionally include a cooling channel 104 that receives airflow through a cooling air intake 110. In certain cases, the rabble arms 103 may also include cooling channels. In these examples where the rabble arm shaft 117 and/or the rabble arms 103 include cooling channels, gases may be moved through the scrap material via the cooling channels. For example and without limitation, gases heated to a desired temperature may be channeled through the cooling channels and out openings defined in the rabble arm shaft 117 and/or rabble arms 103 to distribute the hot gas into the scrap material. Distribution of the hot gas via the cooling channels may increase the gas to shred contact ratio, which may improve decoating and reduce required dwell time within the

hearth 101. Additionally, hot gas having low oxygen levels moved through the rabble arm shaft 117 can be channeled to different hearths 101 as needed.

[0037] In further examples, a floor of the hearth 101 may optionally be a porous screen over which the scrap material is passed. Under the screen, high velocity hot gases at the desired temperature can be passed through the porous screen via nozzles. In these examples, heat transfer coefficients may be increased through the bed of scrap material.

[0038] Depending on process conditions and the material of the rabble arms 103 and rabble arm shaft 117, cooling may be used to prevent cracking, warping, or other damage to the rabble arms 103 and rabble arm shaft 117. Warmed exit air from the cooling channel 104 and having low oxygen levels may be used to dry and/or preheat incoming scrap materials or support combustion.

[0039] The multi-hearth roaster 100 may be heated by a number of burners 201 which may be arranged throughout the multi-hearth roaster 100 according to heating requirements, space constraints, and process conditions such as, but not limited to, atmospheric composition and desired temperature of a particular heating zone 118. Gases from the multiple heating zones 118 containing vaporized or combusted contaminants, combustion byproducts, and heating zone atmospheric gases may be collected in a roaster exhaust duct 107 to be transferred for treatment, use in other processes, or release.

[0040] Figure 2 is a schematic sectional view of a heating zone 118 of the multi-hearth roaster 100 of Figure 1. The heating zone 118 is defined by a hearth 101 which may incorporate one or more hearth passages 102. As described above, rabble arms 103 rotate with a rabble arm shaft 117. The rabble arm shaft 117 may be confined within a fixed shaft 116 that serves as a protective barrier between the rabble arm shaft 117 and the environment of the heating zone 118 and the scrap material (not shown) that is being treated within the heating zone 118. In some cases, a cooling channel 104 receives cooling air to manage the

temperature both of the rabble arm shaft 117 and the heating zone 118. The cooling air passing through the cooling channel 104 may be force driven, such as by a fan or compressor, or it may move through the cooling channel 104 through convection only depending upon the cooling requirements of a particular application.

[0041] During operation, scrap material will enter the heating zone 118 from above and be agitated by the rabble arms 103 while being exposed to heat and, optionally, a reducing, oxidizing or inert atmosphere. As described above, the rabble arms 103 are designed to agitate the scrap metal and gradually shift the scrap metal towards the hearth passage 102. The scrap material can then move from the current heating zone 118 to the next lowest heating zone (not shown) or to a discharge chute to exit the multi-hearth roaster. As the scrap material is agitated and shifted around the heating zone 118, erosion of the hearth 101, heating zone walls, or other parts of the multi-hearth roaster may become problematic. Selected areas of the heating zone 118 may be lined with stainless steel or other materials to prevent or eliminate erosion or premature wear.

[0042] As shown in Figure 2, the hearth 101 is depicted as a flat surface for holding scrap material while it is agitated and moved by the rabble arms 103. However, the hearth 101 may take on any number of shapes or configurations to provide better mixing of the scrap material, increase or decrease dwell time in the heating zone 118, and/or increase or decrease hearth 101 capacity. For example and without limitation, the hearth 101 may be sloped, dished, or domed having either a concave or convex shape. For example, the hearth 101 can be sloped or curved to direct the scrap material within the hearth 101 towards hearth passages 102. The rabble arms 103 may then be configured to complement the particular shape of the hearth 101.

[0043] The rabble arms 103 may be hinged or otherwise articulate around rabble arm shaft 117 and may include hinged or articulating teeth to more effectively follow the contours of

the hearth 101. The particular design of the rabble arms 103, including the number of arms per hearth 101, their relative spacing, and the design of the rabble arm teeth may be modified as desired for shredded or other types of scrap material. The spacing of the teeth of the rabble arms 103 may be selected based on the average size of the scrap material that is to be processed in the multi-hearth roaster 100. The rabble arms 103 and the movement of the scrap material around and through the hearth 101 will lead relatively even distribution of the scrap material on individual hearths 101 and throughout the multi-hearth roaster 100. In certain cases, the interaction of the rabble arms 103 and larger pieces of scrap material may serve to distribute and/or move smaller pieces of scrap material through the hearths 101 and the multi-hearth roaster 100 during processing.

[0044] Figure 3 is a schematic sectional view of a scrap metal decontamination system 1 including multi-hearth roaster 100 of Figure 1 and a melt furnace 300. As described above, the multi-hearth roaster 100 includes a plurality of hearths 101 having hearth passages 102 and rabble arms 103 that agitate and circulate scrap metal throughout the heating zones 118. As also described above, the scrap material may move from one heating zone 118 to the next lower heating zone 118 through the hearth passages 102 undergoing treatment at different temperatures, pressures, and/or atmospheric compositions until it reaches the final heating zone 118 at the bottom of the multi-hearth roaster 100. In the final heating zone 118, the rabble arms 103 will agitate and move the scrap material until it is discharged from the multi-hearth roaster 100 through the discharge chute 108. In certain cases, the vertical orientation of the multi-hearth roaster 100 may allow for locating the multi-hearth roaster 100 in close proximity to a melt furnace 300. Locating the multi-hearth roaster 100 closer to the melt furnace 300 may improve process efficiency by reducing or minimizing heat loss of the roasted scrap material as it is transferred to the melt furnace 300. By introducing roasted

scrap material into the melt furnace 300 at a higher temperature, the melt furnace 300 may run at lower power and/or higher efficiency while maintaining or increasing the melt rate.

[0045] Still referring to Figure 3, various strategies may be employed to increase the efficiency of the multi-hearth roaster 100 and the overall recycling process. For example, as shown, the multi-hearth roaster 100 may be positioned or located so that the discharge chute 108 feeds decontaminated scrap material directly into the melt furnace 300. This direct feed arrangement increases process efficiency because the scrap material has little, if any, cooling time between exiting the multi-hearth roaster 100 and entering the melt furnace 300. In turn, less heat may be applied by the melt furnace 300 to the scrap material to melt it down for further processing.

[0046] The multi-hearth roaster 100 may be equipped with a zone-to-zone gas exchange manifold 112 (partially shown). The zone-to-zone gas exchange manifold 112 may be used to direct gases from one heating zone 118 to another. In some cases, it may be desirable to transfer gases from a relatively hotter heating zone 118 to a relatively cooler heating zone 118. The transfer of gases from a relatively hotter heating zone 118 to a relatively cooler heating zone 118 reduces the amount of heating required of the burners 201, reducing the energy consumption of the overall scrap decontamination process. In certain cases, the zone-to-zone gas exchange manifold 112 may be used to direct gases from a relatively cooler heating zone 118 to a relatively hotter heating zone 118. The recirculated gases from the relatively cooler heating zone 118 can be used to control the temperature of the relatively hotter heating zone 118 to maintain optimal process temperatures. Gases from the multi-hearth roaster 100 heating zones 118 are then collected in the roaster exhaust duct 107 and transferred to a scrubber, other processes, or emitted into the air. Proper ducting of gases through the zone-to-zone gas exchange manifold 112 and the roaster exhaust duct 107 can

provide improved control of atmospheric composition and pressure within the heating zones 118.

[0047] Figures 4 and 5 are sectional illustrations of a scrap metal decontamination system 1 including multi-hearth roaster 100 and an external heat source 200, which may be an incinerator, a boiler, electric furnace, gas fired furnace, or other burner system. As described above, multi-hearth roaster 100 includes a plurality of hearths 101 which define a plurality of heating zones 118. Each heating zone 118 may be maintained at its own specified pressure, temperature, and atmospheric composition to affect a different heating process within that heating zone 118 compared to the other heating zones 118. In some examples, heated gases from integrated heat sources, such as integrated burners 201 or the external heat source 200, may be fed into the multi-heart roaster 100 and flow through the heating zones 118 to directly heat scrap material via conduction. In some examples, depending on the fuel source and temperature at which toxins are removed, the furnace gases may need to be cooled through air and/or nitrogen or other gases to avoid overheating and melting of the scrap material, as illustrated in Figures 6A and 6B.

[0048] Rabble arms 103 connected to a rabble arm shaft 117 rotate within the heating zones 118 to agitate and move scrap material throughout the heating zones 118 and to assist in moving scrap material from the top heating zone 118 to the bottom heating zone 118. Scrap material enters the top of the multi-hearth roaster 100 through an inlet feed 106 and moves through successive heating zones 118 until it reaches the bottom heating zone 118 of the multi-hearth roaster 100. After the scrap material has moved through each of the heating zones 118, it is discharged from the multi-hearth roaster 100 through the discharge chute 108. Because sealing of the multi-hearth roaster 100 is important to maintaining ideal processing conditions, the scrap metal decontamination system 1 may include a discharge chute air lock 109 to help prevent leakage of process gases. The scrap metal decontamination system may

include a salt injection apparatus 105 to inject salts to the decontaminated scrap material. The salts, which are mixed in with the decontaminated scrap material, are helpful during the melting phase of recycling to create dross and remove any additional contaminants from the scrap material. In certain cases, the lowest heating zone 118 may be filled with a salt containing plasma atmosphere to deposit a thin coating of salt on the scrap without the need for a salt injection apparatus 105 or salt additions in later steps of the recycling process. In some aspects, a final section of the multi-hearth roaster 100 may comprise a high temperature plasma burner to melt a fluxing salt and coat the scrap with eutectic salt prior to addition of the scrap in the melting furnace.

[0049] The external heat source 200, which may include an electrical heating element or burner 201 adapted to burn any type of fuel source, has a series of exhaust ducts 202 which transfer hot gases to the multi-hearth roaster 100 heating zones 118 to maintain appropriate temperatures in the heating zones 118. These exhaust ducts 202 may optionally include valves or other flow control devices that allow the flow of hot gases from the external heat source 200 to the heating zones 118 to be controlled and provide relatively more or less heating to any particular heating zone 118. The control of gas flow from the external heat source 200 to the heating zones 118 allows for the heating zones 118 to be maintained at different temperatures so that the scrap material may be processed through different heating stages at different temperatures. The external heat source 200 also includes an exhaust stack 203 for venting waste gases that may be processed by incinerators, heat exchangers, water scrubbers, and baghouses prior to their release into the environment. In certain cases, a heat exchanger or other power generating device may be attached or otherwise in communication with the external heat source 200 to retrieve excess energy from the external heat source 200. The heat exchanger or other power generating device may then produce power that may be

used in the multi-hearth roaster 100 or to run ancillary processes or equipment within the facility.

[0050] Still referring to Figures 4 and 5, the scrap metal decontamination system 1 may be a closed loop system which reuses and redistributes process gases to more efficiently heat and process the scrap materials. The rabble arm shaft 117 may include a cooling channel 104 connected to a cooling air intake 110. Cooling air enters the cooling channel 104 at the bottom of the multi-hearth roaster 100 and moves upwards towards the top of the multi-hearth roaster 100. As the cooling air exits the cooling channel 104, the air has gained a significant amount of heat. At this point, the cooling air from the cooling channel 104 may be routed into the combustion air duct 113 and into the external heat source 200. Pre-heated air from the cooling channel 104 allows for more efficient combustion in the external heat source 200, reducing fuel usage and emissions.

[0051] The multi-hearth roaster 100 may also include a zone-to-zone gas exchange manifold 112 adapted to exchange or direct gases between the individual heating zones 118. The zone-to-zone gas exchange manifold 112 may be used to increase efficiency or to achieve more accurate control over the temperature of the heating zones 118. For example, the zone-to-zone gas exchange manifold 112 may be used to direct process gases from relatively hotter heating zones 118 to relatively cooler heating zones 118. This redirection of gases heats the relatively cooler heating zones 118 with waste heat from the relatively hotter heating zones 118, reducing the load on the external heat source 200. Alternatively, the zone-to-zone gas exchange manifold 112 may direct gases from relatively cooler heating zones 118 to relatively hotter heating zones 118 to quickly cool a heating zone 118 that may have exceeded its desired operating temperature. Optionally, a recirculation blower 111 may allow for more efficient and effective transfer of gases through the zone-to-zone gas exchange manifold 112.

[0052] The scrap metal decontamination system 1 may also take advantage of the combustible nature of the vaporized contaminants present in the scrap materials to improve process efficiency and reduce the amount of fuel required to maintain proper temperature in the heating zones 118. As shown in Figures 4 and 5, the roaster exhaust duct 107 may act as a waste gas recycling duct to collect gases from the multi-hearth roaster 100 and route them into the external heat source 200. By rerouting the roaster exhaust duct 107 back into the external heat source, vaporized contaminants from the scrap material can be used to power the decontamination process. Furthermore, directing gases from the heating zones 118 of the multi-hearth roaster 100 may have additional environmental benefits. Certain chemical compounds such as, but not limited to, phosgene and dioxins, may be resistant to breakdown or decomposition at the temperatures present in the heating zones 118 of the multi-hearth roaster 100. Toxic or polluting chemical compounds may be present in the scrap material contaminants, or the heat, pressure, and chemical composition of the scrap material contaminants and heating zone 118 atmosphere may react to form harmful chemicals. Directing the multi-hearth roaster 100 exhaust to the external heat source 200 allows these potentially dangerous compounds to be exposed to much higher temperatures of combustion within the external heat source 200 where they may break down, burn, or otherwise react into more benign chemical constituents and provide additional heat that may be directed to the multi-hearth roaster 100 to aid the decontamination process.

[0053] Referring to Figures 1-5, control over the atmospheric composition of the heating zones 118, particularly for levels of oxygen and vaporized contaminants, may be necessary to ensure safe, efficient roasting of metal scrap in the multi-hearth roaster 100. During roasting, controlling atmospheric composition will allow the scrap material to smoke, indicating that contaminants are being vaporized. However, while some concentration of oxygen in the atmosphere of a heating zone 118 may be unavoidable and/or necessary for

pyrolysis of contaminants and/or VOCs, the levels must be held below certain thresholds to prevent light-off and combustion of the vaporized contaminants and/or VOCs within the heating zone 118. If the atmospheric oxygen and contaminants and/or VOCs ignite, they may raise heating zone 118 temperatures high enough to melt the scrap metal, particularly in the case of aluminum. Molten metal in the heating zone 118 may lead to damage to the multi-hearth roaster 100, rabble arms 103, or other associated equipment, and may also cause safety hazards such as explosions or uncontrolled combustion.

[0054] During processing, it may be preferable to maintain oxygen concentrations below approximately five percent in one or more of the heating zones 118. In certain cases, it may be preferable to maintain oxygen concentration below approximately three percent within one or more of the heating zones 118. Similarly, atmospheric concentrations of vaporized contaminants and/or VOCs may be preferably maintained below approximately ten percent, or, more preferably, maintained below approximately eight percent. With atmospheric concentrations held within these ranges, the atmosphere within the heating zone 118 will allow for vaporizing contaminants and/or VOCs off the metal scrap but prevent ignition and combustion of the gases within the heating zone 118. The mixture of gases may then be collected and directed to an incinerator or other burners 201 for use as a heat source during processing.

[0055] The multi-hearth roaster 100 allows for processing of metal scrap with higher levels of contaminants and/or VOCs because the atmospheres of the individual heating zones 118 experience relatively low levels of atmospheric gas exchange, unless purposely directed through the use of a zone-to-zone gas exchange manifold 112. As metal scrap moves through the heating zones 118 from lower to higher temperatures, different contaminants and/or VOCs will be gradually burned off in stages according to the temperatures at which they vaporize. Only those contaminants or VOCs which vaporize at the temperatures in a

particular heating zone 118 will become part of the heating zone 118 atmosphere. For example, in the first heating zone 118, of lowest temperature, the atmosphere will only contain vapors from contaminants and/or VOCs that vaporize at the lowest temperatures. Any contaminants and/or VOCs that vaporize at higher temperatures will remain in solid or liquid states, and will not enter the atmosphere of the heating zone 118. As a result, the atmosphere is less likely to exceed thresholds for safe processing because only subset of contaminants and/or VOCs will enter the atmosphere of the heating zone 118. In later heating zones 118 of higher temperature, the next subset of contaminants and/or VOCs will be vaporized. However, in this higher temperature heating zone 118, all or a significant percentage of contaminants and/or VOCs which vaporize at lower temperatures will have been removed and will have little if any influence on the atmospheric composition. Scrap material with higher concentrations of contaminants and/or VOCs may be safely and efficiently roasted with this staged heating process. Furthermore, progressive heating of scrap material allows for one or more of the later heating zones 118 to be held at much higher temperatures. The final stage or stages of heating will safely remove a greater percentage of contaminants or VOCs than treatment in a traditional rotary kiln, which may not safely operate at such high temperatures. The resulting scrap material is cleaner and less likely to form reaction products and dross when it is subsequently melted down for recycling.

[0056] The multi-hearth roaster 100 may include contra-flowing scrap material and gases. Scrap material may enter the multi-hearth roaster 100 at the upper-most heating zone 118. Rabble arms 103 will agitate and displace the scrap material towards hearth passages 102 where scrap material may be fed by gravity into the next lowest heating zone 118. The scrap material will continue to move through progressively lower heating zones 118 until reaching the lowest heating zone 118 and exiting the multi-hearth roaster 100 through the discharge chute 108. Conversely, heated gases, either from integrated heat sources, such as integrated

burners 201 or the external heat source 200 may be fed in to the lowest heating zone 118 and flow vertically up from the lowest heating zone 118 to the upper-most heating zone 118. The heated gases from integrated burners 201 or the external heat source 200 will be hottest as they enter the multi-hearth roaster 100, and consequently the lowest heating zone 118 will, without other adjustments such as water sprays or zone-to-zone gas exchange, operate at the highest temperature. Successively higher heating zones 118 will operate at successively lower temperatures with the upper-most heating zone 118 having the lowest temperature. As the scrap material moves from top to bottom through the multi-hearth roaster 100, and hot gases move from bottom to top, the scrap material will move through the heating zones 118 from relatively lower to progressively higher temperatures. Contaminants in the scrap material will be burned, decomposed, or vaporized in succession depending on their heat of vaporization and tolerance for temperature. This stepped removal of contaminants allows the multi-hearth roaster 100 to process more varied, heterogeneous scrap materials containing higher levels of contamination with reduced risk of fire or explosion. In examples where each hearth 101 may be individually controlled, each hearth 101 can be configured to have set points for oxygen levels, temperature, pressure, and various other properties.

[0057] Still referring to Figures 1-5, in certain cases the scrap metal decontamination system 1 and/or multi-hearth roaster 100 may include control systems and/or mechanisms designed to maintain the conditions of the scrap metal decontamination system 1 and/or multi-hearth roaster 100 within specified ranges as required by the type of scrap metal being processed, the type of contaminants to be removed, and/or the desired throughput or mass flow rates of the multi-hearth roaster 100. In certain cases, the control systems may feature feedback loops, predictive models, and/or other control strategies to determine how one or more control devices may be used to influence the conditions of the scrap metal decontamination system 1 and/or multi-hearth roaster 100 and maintain the desired process

parameters or conditions during operation. In some cases, the control system may influence the operation of the scrap metal decontamination system 1 and/or multi-hearth roaster 100 as a whole, or it may influence the operation of one or more of the heating zones 118 individually.

[0058] For example, the scrap metal decontamination system 1 and/or multi-hearth roaster 100 may incorporate direct or indirect sensing of the temperature of one or more of the heating zones 118. Temperature measurements may be made directly, such as but not limited to, with a thermistor, thermocouple, or other temperature sensor, or they may be made indirectly as with measurements of heat source output, modeling, or other methods for inferring or indirectly determining the temperatures of the heating zones 118. The temperature measurement may then be converted into a signal and delivered or otherwise transmitted to a control system and/or temperature control device. The temperature control device may then be used to increase or decrease the temperature in one or more of the heating zones 118. In some cases, the temperature control device may include one or more of a source of hot gases, a source of cold gases, a venting mechanism, an external burner, an integrated burner, an external heat source, water, or an integrated heat source to raise, lower, or maintain the temperature within one or more of the heating zones 118. In certain cases, the temperature control devices may include one or more of the roaster exhaust duct 107, the zone-to-zone gas exchange manifold 112, external heat source 200, and/or burners 201 that may already be in use in the scrap metal decontamination system 1. In other cases, the temperature control devices may be separate equipment that would not otherwise be included in the scrap metal decontamination system 1.

[0059] Similarly, the scrap metal decontamination system 1 and/or multi-hearth roaster 100 may have a system for adjusting and/or maintaining atmospheric conditions within the heating zones 118. The chemical composition and/or pressure within the heating

zones 118 may be directly measured, as with sensors, or indirectly measured through the use of mathematical models or other inferential measurement techniques. These measured or inferred values may then be converted into a signal and transmitted or otherwise delivered to a control system or atmosphere control device. The atmosphere control device may then be used to alter the chemical composition and/or pressure of the gases within the heating zones 118. For example, in certain cases the atmosphere control device may include one or more of a valve body, pressurized or unpressurized gas reservoirs to introduce gases into the heating zones 118, ducting systems for directing gas flows, a venting system, and/or controls mechanisms that alter the air-to-fuel ratio of a combustion-based heating system to influence the composition of heated combustion gases. In some cases, the atmosphere control devices may include one or more of the roaster exhaust duct 107, the zone-to-zone gas exchange manifold 112, external heat source 200, and/or burners 201, which may be used to influence the gas flows or exchanges between individual heating zones 118 and/or the exchange of gases within the multi-hearth roaster 100 and the ambient air. The control system may then maintain desired levels of oxygen, inert gases, combustion products, vaporized contaminants, water vapor, organics, or other chemical components and their relative or combined pressures. These devices may work alone or in combination with other control equipment. In certain cases, a system of valves may be used to control and adjust gas flows between any constituent part of the scrap metal decontamination system 1.

[0060] Figures 6A and 6B illustrate a schematic view of an example of a multi-hearth roaster system 630 with the external incinerator 200 and the gas control manifold 112. As illustrated, the system 630 may include the burner 201, a combustion air blower 632, and combustion box separate 634 from the multi-hearth roaster 100. Cooling air enters the multi-hearth roaster 100 through the cooling air intake 110. The cooling air moves upwards towards the top of the multi-hearth roaster 100 through the rabble arm shaft 117. As

previously described, the rabble arm shaft 117 may be rotated through the drive motor 114 to rotate the rabble arms 103 (not illustrated in Figures 6A and 6B). Hot gases may flow from the combustion box 634 to individual heating zones 118 of the multi-hearth roaster 100 via the gas control manifold 112. One branch of the gas control manifold 112 leading to one of the heating zones 118 is illustrated in Figure 6B. As illustrated in Figure 6B, in some examples, air, nitrogen, or various other gases or combinations of gases may be introduced to the system via valves 636A–C of the gas manifold 112. In some examples, the temperature of these gases may be lower relative to the temperature of the hot gas from the combustion box 634 such that they can mix to control the temperature within the heating zones 118. As illustrated in Figures 6B, in some aspects, the gas manifold 112 may have control sensors 638 including, but not limited to, temperature sensors, oxygen sensors, pressure sensors, and/or various other types of sensors. In various examples, each branch of the gas control manifold 112 may be configured to provide hot gases to an individual heating zone 118. In other aspects, each branch of the gas control manifold 112 may be controlled independently from the other branches such that temperature profiles in the different heating zones 118 can be varied.

[0061] Referring to Figure 6A, in some examples, each hearth 101 may include control sensors 638. As one non-limiting example, the control sensors 638 are pressure gauge controls, but they may be any suitable sensor. In some examples, the contaminants removed from the scrap material within the multi-hearth roaster 100 are vented from the hearths and drawn into the incinerator via a fan or other mechanism for forcing gas movement. The contaminants may be used by the incinerator 200 as a fuel source, as described previously. Some of the energy generated by the incinerator is recycled back to the multi-hearth roaster. In some examples, any excess energy may be filtered of toxins, such as through a baghouse 640, and vented into the atmosphere or used for other purposes including, but not limited to,

running a Rankine cycle engine to produce electricity or hot water. In one non-limiting example, the baghouse 640 is a hot baghouse with absorbent material to filter out particulates from the vented gas.

[0062] Different arrangements of the components depicted in the drawings or described above, as well as components and steps not shown or described are possible. Similarly, some features and subcombinations are useful and may be employed without reference to other features and subcombinations. Embodiments of the invention have been described for illustrative and not restrictive purposes, and alternative embodiments will become apparent to readers of this patent. Accordingly, the present invention is not limited to the embodiments described above or depicted in the drawings, and various embodiments and modifications can be made without departing from the scope of the claims below.

[0063] A collection of exemplary embodiments, including at least some explicitly enumerated as “ECs” (Example Combinations), providing additional description of a variety of embodiment types in accordance with the concepts described herein are provided below. These examples are not meant to be mutually exclusive, exhaustive, or restrictive; and the invention is not limited to these example embodiments but rather encompasses all possible modifications and variations within the scope of the issued claims and their equivalents. As used below, any reference to a series of examples is to be understood as a reference to each of those examples disjunctively (e.g., “Examples 1-4” is to be understood as “Examples 1, 2, 3, or 4”).

[0064] EC 1 is a scrap metal treatment system comprising: a multi-hearth roaster comprising a plurality of heating zones and a plurality of rabble arms; wherein the plurality of heating zones are arranged in a vertical stack such that scrap metal may enter a highest heating zone and move to a lowest heating zone to exit the multi-hearth roaster; and wherein

each heating zone of the plurality of heating zones comprises a temperature different from the temperature of a preceding heating zone of the plurality of heating zones.

[0065] EC 2 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein the temperatures of the plurality of heating zones are within a range of about 350 degrees Celsius to about 550 degrees Celsius.

[0066] EC 3 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein each of the plurality of heating zones comprises a temperature lower than the temperature of the next lowest of the plurality of heating zones.

[0067] EC 4 is the scrap metal treatment system of any of the preceding or subsequent example combinations, further comprising a temperature sensor in communication with at least one of the plurality of heating zones, wherein the temperature sensor provides a feedback signal to a temperature control device to maintain the temperature of at least one of the plurality of heating zones within a specified range.

[0068] EC 5 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein the temperature control device comprises a venting mechanism, a hot gas source, a cold gas source, an external burner, an integrated burner, an external heat source, or an integrated heat source.

[0069] EC 6 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein at least one of the plurality of heating zones comprises a water spray.

[0070] EC 7 is the scrap metal treatment system of any of the preceding or subsequent example combinations, further comprising a zone-to-zone gas exchange manifold.

[0071] EC 8 is the scrap metal treatment system of any of the preceding or subsequent example combinations, further comprising an external heat source.

[0072] EC 9 is the scrap metal treatment system of any of the preceding or subsequent example combinations, further comprising a heat exchanger in communication with the external heat source; wherein the heat exchanger generates power from excess heat of the external heat source.

[0073] EC 10 is the scrap metal treatment system of any of the preceding or subsequent example combinations, further comprising a waste gas recycling duct configured to direct waste gases of at least one of the plurality of heating zones to the external heat source.

[0074] EC 11 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein the waste gases comprise dioxins.

[0075] EC 12 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein the waste gases comprise phosgene.

[0076] EC 13 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein at least one of the plurality of heating zones comprises an integrated heat source.

[0077] EC 14 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein the integrated heat source comprises a burner.

[0078] EC 15 is the scrap metal treatment system of any of the preceding or subsequent example combinations, further comprising an atmosphere composition sensor in communication with at least one of the plurality of heating zones; wherein the atmosphere composition sensor provides a feedback signal to an atmosphere control device to maintain the atmospheric composition of at least one of the plurality of heating zones within a specified range.

[0079] EC 16 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein the atmosphere control device comprises a valve system, a vent system, or pressurized gas reservoirs.

[0080] EC 17 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein at least one of the plurality of heating zones comprises an inert atmosphere.

[0081] EC 18 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein at least one of the plurality of heating zones comprises a reducing atmosphere.

[0082] EC 19 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein at least one of the plurality of heating zones comprises an oxidizing atmosphere.

[0083] EC 20 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein at least one of the plurality of heating zones comprises a sloped hearth.

[0084] EC 21 is the scrap metal treatment system of any of the preceding or subsequent example combinations, wherein each of the plurality of heating zones contains at least one of the plurality of rabble arms.

[0085] EC 22 is a method for processing scrap metal for recycling, the method comprising: providing a plurality of heating zones, wherein each heating zone of the plurality of heating zones comprises a temperature different from the temperature of a preceding heating zone of the plurality of heating zones; and passing scrap metal through successive heating zones of the plurality of heating zones.

[0086] EC 23 is the method of any of the preceding or subsequent example combinations, wherein the temperatures of the plurality of heating zones are within a range of about 350 degrees Celsius to about 550 degrees Celsius.

[0087] EC 24 is the method of any of the preceding or subsequent example combinations, wherein each successive heating zone of the plurality of heating zones comprises a temperature higher than the preceding heating zone of the plurality of heating zones.

[0088] EC 25 is the method of any of the preceding or subsequent example combinations, further comprising: sensing a temperature of at least one of the plurality of heating zones; providing a feedback signal from the temperature of at least one of the plurality of heating zones to a temperature control device; and maintaining the temperature of the at least one of the plurality of heating zones within a specified range.

[0089] EC 26 is the method of any of the preceding or subsequent example combinations, wherein maintaining the temperature of the at least one of the plurality of heating zones within the specified range comprises controlling a venting mechanism, introducing hot gas into at least one of the plurality of heating zones, introducing cold gas into at least one of the plurality of heating zones, controlling an external burner, controlling an integrated burner, controlling an external heat source, or controlling an integrated heat source.

[0090] EC 27 is the method of any of the preceding or subsequent example combinations, further comprising injecting water into at least one of the plurality of heating zones.

[0091] EC 28 is the method of any of the preceding or subsequent example combinations, further comprising controlling the atmospheric composition of at least one of the plurality of heating zones.

[0092] EC 29 is the method of any of the preceding or subsequent example combinations, further comprising: providing an atmosphere composition sensor in communication with at least one of the plurality of heating zones; providing a feedback signal to an atmosphere composition control device; and maintaining the atmospheric composition of at least one of the plurality of heating zones within a specified range.

[0093] EC 30 is the method of any of the preceding or subsequent example combinations, wherein maintaining the atmospheric composition of at least one of the plurality of heating zones within the specified range comprises venting at least one of the plurality of heating zones, introducing gases to at least one of the plurality of heating zones, or changing a pressure within at least one of the plurality of heating zones.

[0094] EC 31 is the method of any of the preceding or subsequent example combinations, wherein the atmospheric composition of at least one of the plurality of heating zones comprises an inert atmosphere.

[0095] EC 32 is the method of any of the preceding or subsequent example combinations, wherein the atmospheric composition of at least one of the plurality of heating zones comprises a reducing atmosphere.

[0096] EC 33 is the method of any of the preceding or subsequent example combinations, wherein the atmospheric composition of at least one of the plurality of heating zones comprises an oxidizing atmosphere.

[0097] EC 34 is the method of any of the preceding or subsequent example combinations, further comprising exchanging gases between the plurality of heating zones.

[0098] EC 35 is the method of any of the preceding or subsequent example combinations, further comprising heating the plurality of heating zones with an external heat source.

[0099] EC 36 is the method of any of the preceding or subsequent example combinations, further comprising providing a heat exchanger in communication with the external heat source; generating power from excess heat of the external heat source.

[0100] EC 37 is the method of any of the preceding or subsequent example combinations, further comprising directing a waste gas from at least one of the plurality of heating zones to the external heat source.

[0101] EC 38 is the method of any of the preceding or subsequent example combinations, wherein the waste gas comprises dioxin.

[0102] EC 39 is the method of any of the preceding or subsequent example combinations, wherein the waste gas comprises phosgene.

[0103] EC 40 is the method of any of the preceding or subsequent example combinations, wherein at least one of the plurality of heating zones is heated with an integrated heat source.

[0104] EC 41 is the method of any of the preceding or subsequent example combinations, wherein the integrated heat source comprises a burner.

[0105] EC 42 is a method for processing heterogeneous scrap metal for recycling, the method comprising: providing a plurality of heating zones, wherein each heating zone of the plurality of heating zones comprises a temperature different from the temperature of a preceding heating zone of the plurality of heating zones; and passing scrap metal through successive heating zones of the plurality of heating zones.

Claims

That which is claimed is:

1. A scrap metal treatment system comprising:

a multi-hearth roaster comprising a plurality of heating zones and a plurality of rabble arms;

a zone-to-zone gas exchange manifold;

an external heat source; and

a waste gas recycling duct;

wherein the plurality of heating zones are arranged in a vertical stack such that scrap metal may enter a highest heating zone and move to a lowest heating zone to exit the multi-hearth roaster,

wherein each of the plurality of heating zones comprises at least one of the plurality of rabble arms to agitate and move the scrap metal through the plurality of heating zones, the zone-to-zone gas exchange manifold may move gases between the plurality of heating zones, and the waste gas recycling duct may direct waste gases from at least one of the plurality of heating zones to the external heat source; and

wherein each heating zone of the plurality of heating zones comprises a temperature lower than a temperature of a next lowest heating zone of the plurality of heating zones, and wherein each of the temperatures of the plurality of heating zones are within a range of about 350 degrees Celsius to about 550 degrees Celsius, and wherein each heating zone of the plurality of heating zones comprises a controlled atmosphere that is inert, reducing, or oxidizing.

2. The scrap metal treatment system of claim 1, further comprising a temperature sensor in communication with at least one of the plurality of heating zones; and

a temperature control device selected from the group consisting of a venting mechanism, a hot gas source, a cold gas source, an external burner, an integrated burner, the external heat source, and an integrated heat source,

wherein the temperature sensor provides a feedback signal to the temperature control device to maintain the temperature of at least one of the plurality of heating zones within a specified range.

3. The scrap metal treatment system of any of the preceding claims, wherein at least one of the plurality of heating zones comprises a water spray.

4. The scrap metal treatment system of any of the preceding claims, further comprising a heat exchanger in communication with the external heat source,

wherein the heat exchanger generates power from excess heat of the external heat source.

5. The scrap metal treatment system of any of the preceding claims, wherein the waste gases comprise dioxins or phosgene.

6. The scrap metal treatment system of any of the preceding claims, wherein at least one of the plurality of heating zones comprises an integrated heat source.

7. The scrap metal treatment system of claim 6, wherein the integrated heat source comprises a burner or electric heater.

8. The scrap metal treatment system of any of the preceding claims, further comprising an atmosphere composition sensor in communication with at least one of the plurality of heating zones; and

an atmosphere control device selected from the group consisting of a valve system, a vent system, and pressurized gas reservoirs,

wherein the atmosphere composition sensor provides a feedback signal to the atmosphere control device to maintain an atmospheric composition of at least one of the plurality of heating zones within a specified range.

9. The scrap metal treatment system of claim 1, wherein at least one of the plurality of heating zones comprises a sloped hearth.

10. A method for processing scrap metal for recycling with the scrap metal treatment system of claim 1, the method comprising:

providing the plurality of heating zones, wherein each heating zone of the plurality of heating zones comprises a temperature higher than a temperature of a preceding heating zone of the plurality of heating zones;

exchanging gases between the plurality of heating zones;

heating the plurality of heating zones with the external heat source;

directing the waste gas from at least one of the plurality of heating zones to the external heat source; and

passing scrap metal through successive heating zones of the plurality of heating zones,

wherein each of the temperatures of the plurality of heating zones are within a range of about 350 degrees Celsius to about 550 degrees Celsius.

11. The method of claim 10, further comprising:
- sensing the temperature of at least one of the plurality of heating zones;
 - providing a feedback signal from the temperature of at least one of the plurality of heating zones to a temperature control device; and
 - maintaining the temperature of the at least one of the plurality of heating zones within a specified range,
- wherein maintaining the temperature of the at least one of the plurality of heating zones is selected from the group consisting of controlling a venting mechanism, introducing hot gas into at least one of the plurality of heating zones, introducing cold gas into at least one of the plurality of heating zones, controlling an external burner, controlling an integrated burner, controlling the external heat source, and controlling an integrated heat source.
12. The method of claims 10 or 11, further comprising injecting water into at least one of the plurality of heating zones.
13. The method of claims 10-12, further comprising controlling an atmospheric composition of at least one of the plurality of heating zones;
- providing an atmosphere composition sensor in communication with at least one of the plurality of heating zones;
 - providing a feedback signal to an atmosphere composition control device; and
 - maintaining the atmospheric composition of at least one of the plurality of heating zones within a specified range,
- wherein maintaining the atmospheric composition of at least one of the plurality of heating zones within the specified range is selected from the group consisting of venting at

least one of the plurality of heating zones, introducing gases to at least one of the plurality of heating zones, and changing a pressure within at least one of the plurality of heating zones.

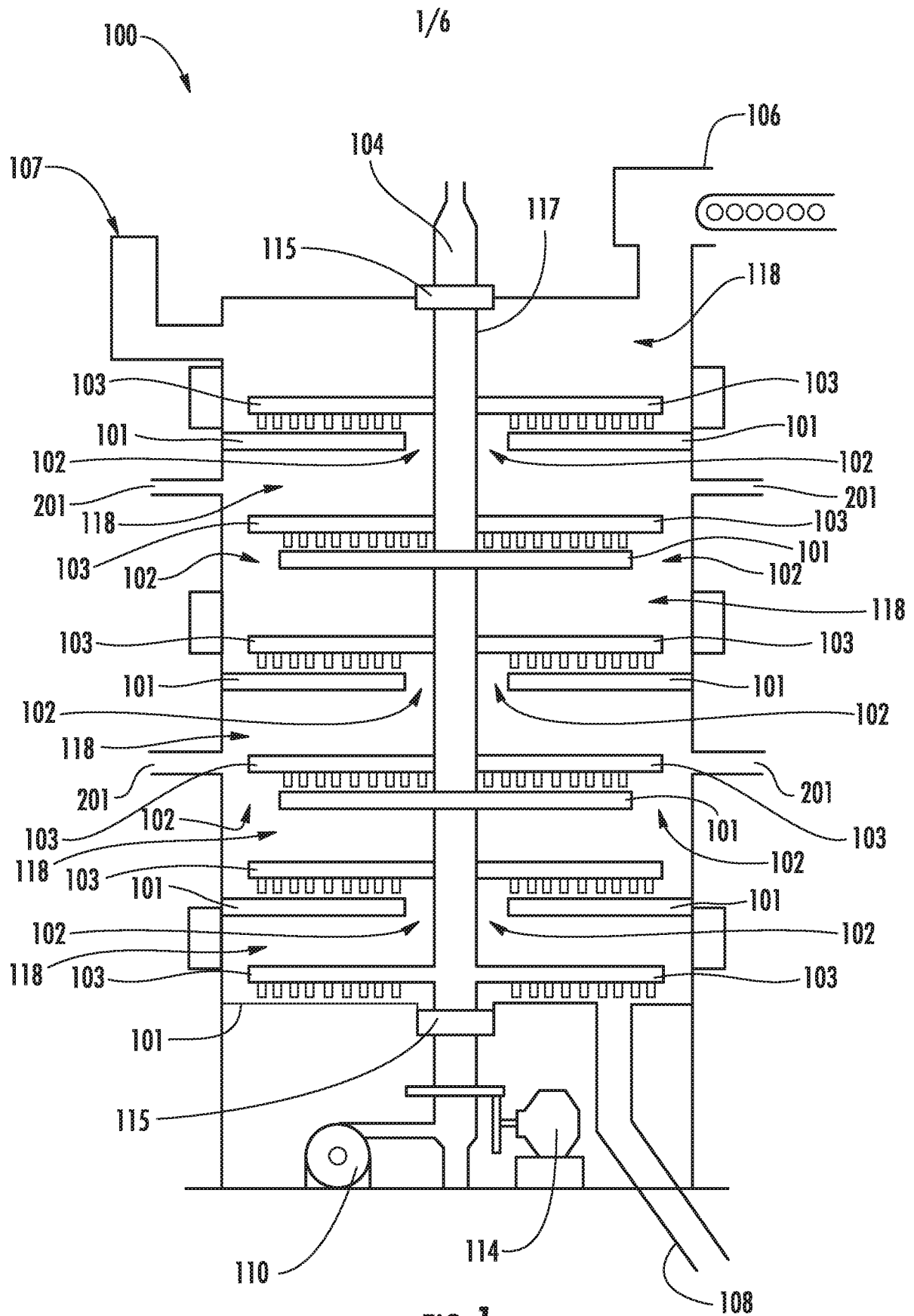
14. The method of claim 13, wherein the atmospheric composition of at least one of the plurality of heating zones is selected from the group consisting of an inert atmosphere, a reducing atmosphere, and an oxidizing atmosphere.

15. The method of claims 10-14, further comprising providing a heat exchanger in communication with the external heat source; and
generating power from excess heat of the external heat source.

16. The method of claims 10-15, wherein the waste gas comprises dioxin or phosgene.

17. The method of claims 10-16, wherein at least one of the plurality of heating zones is heated with an integrated heat source.

18. The method of claim 17, wherein the integrated heat source comprises a burner or electric heater.



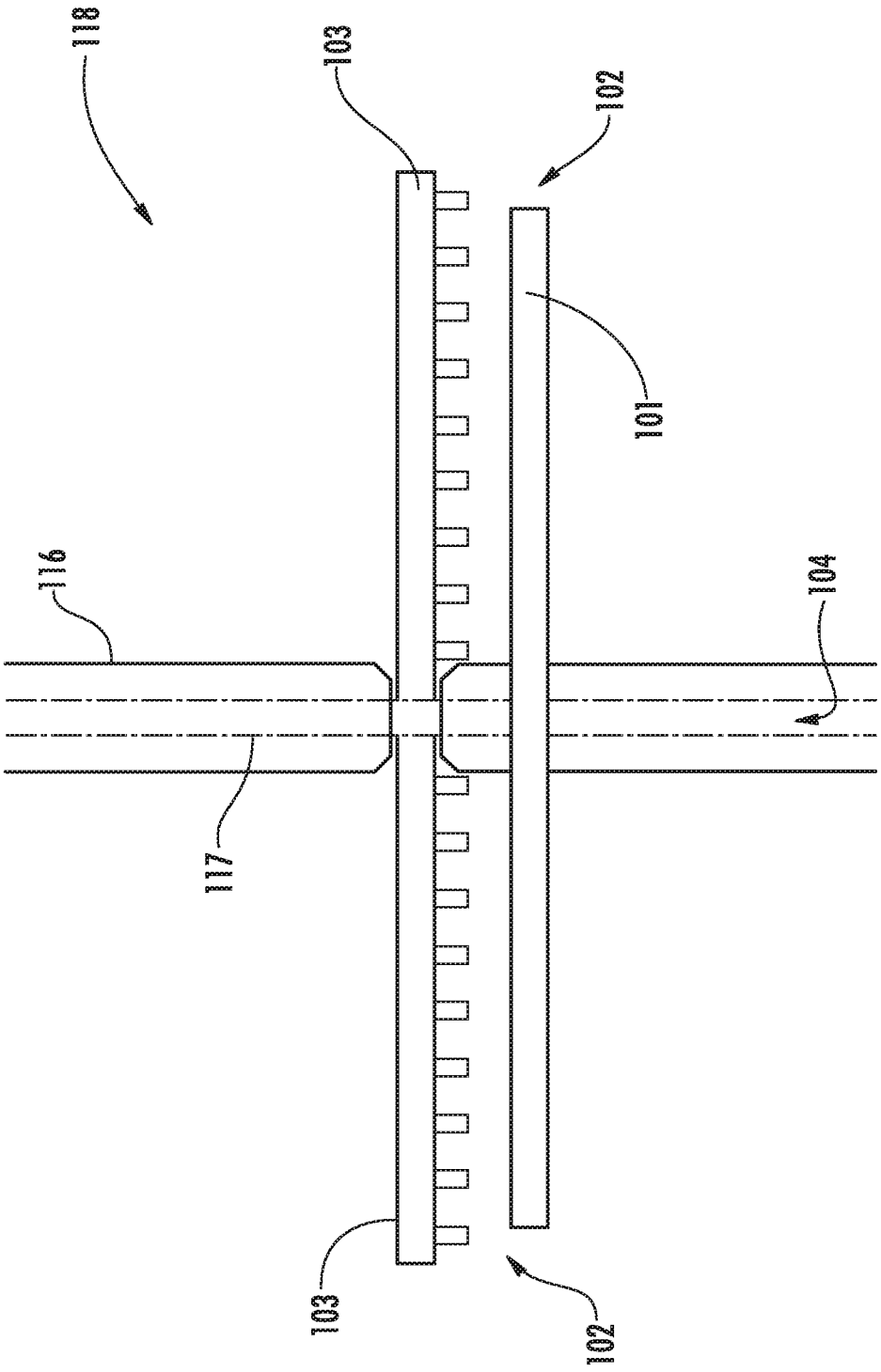


FIG. 2

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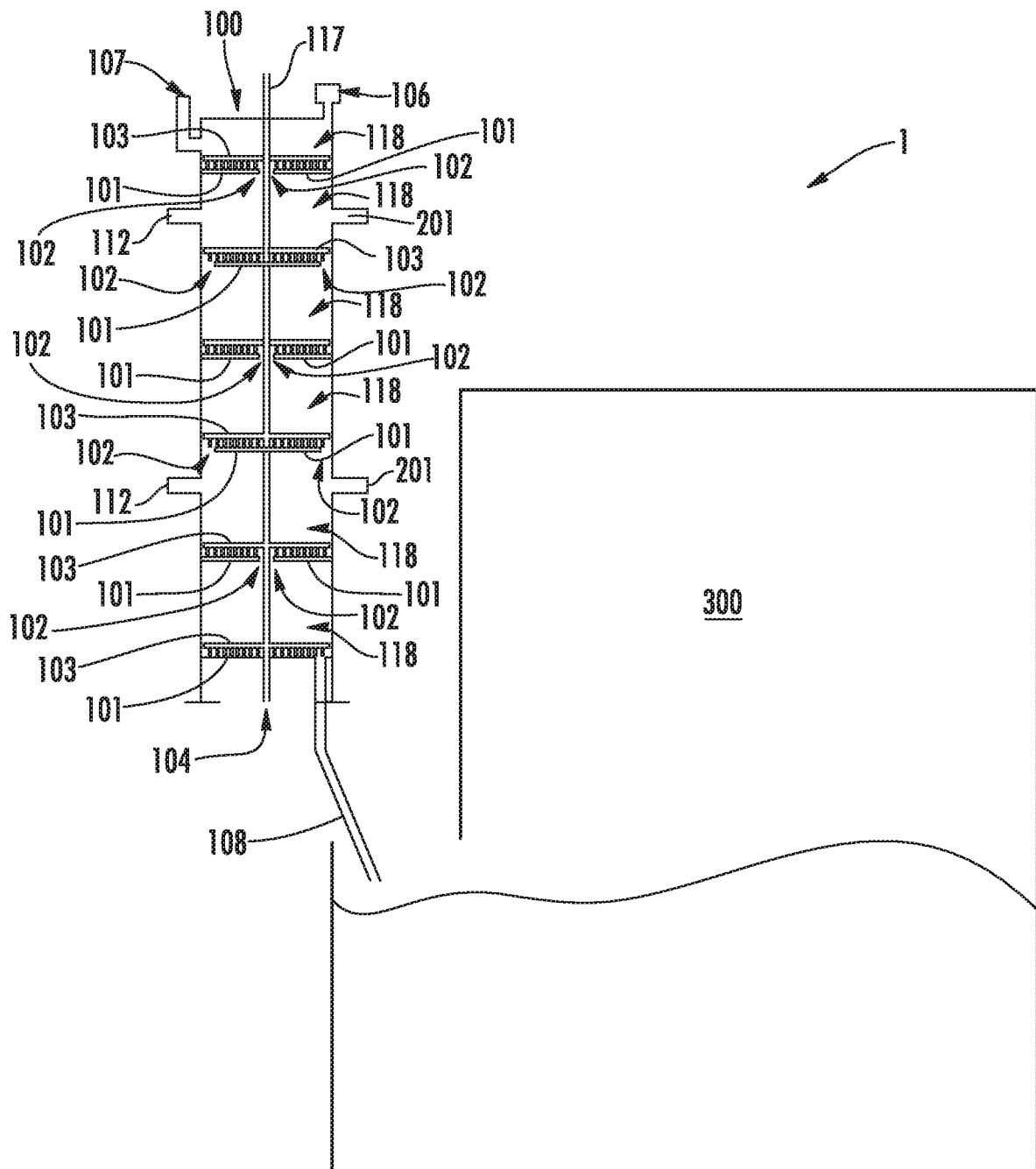
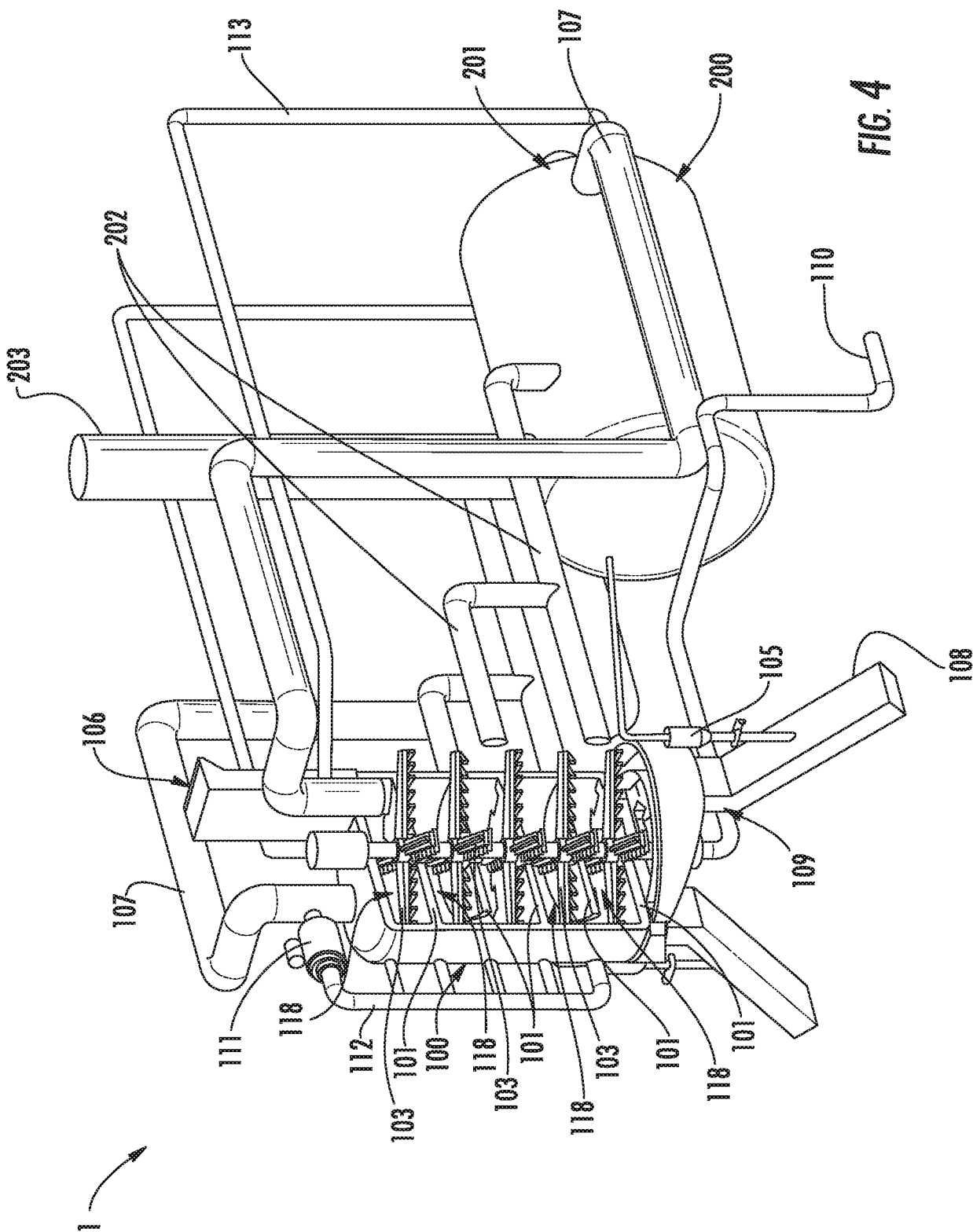
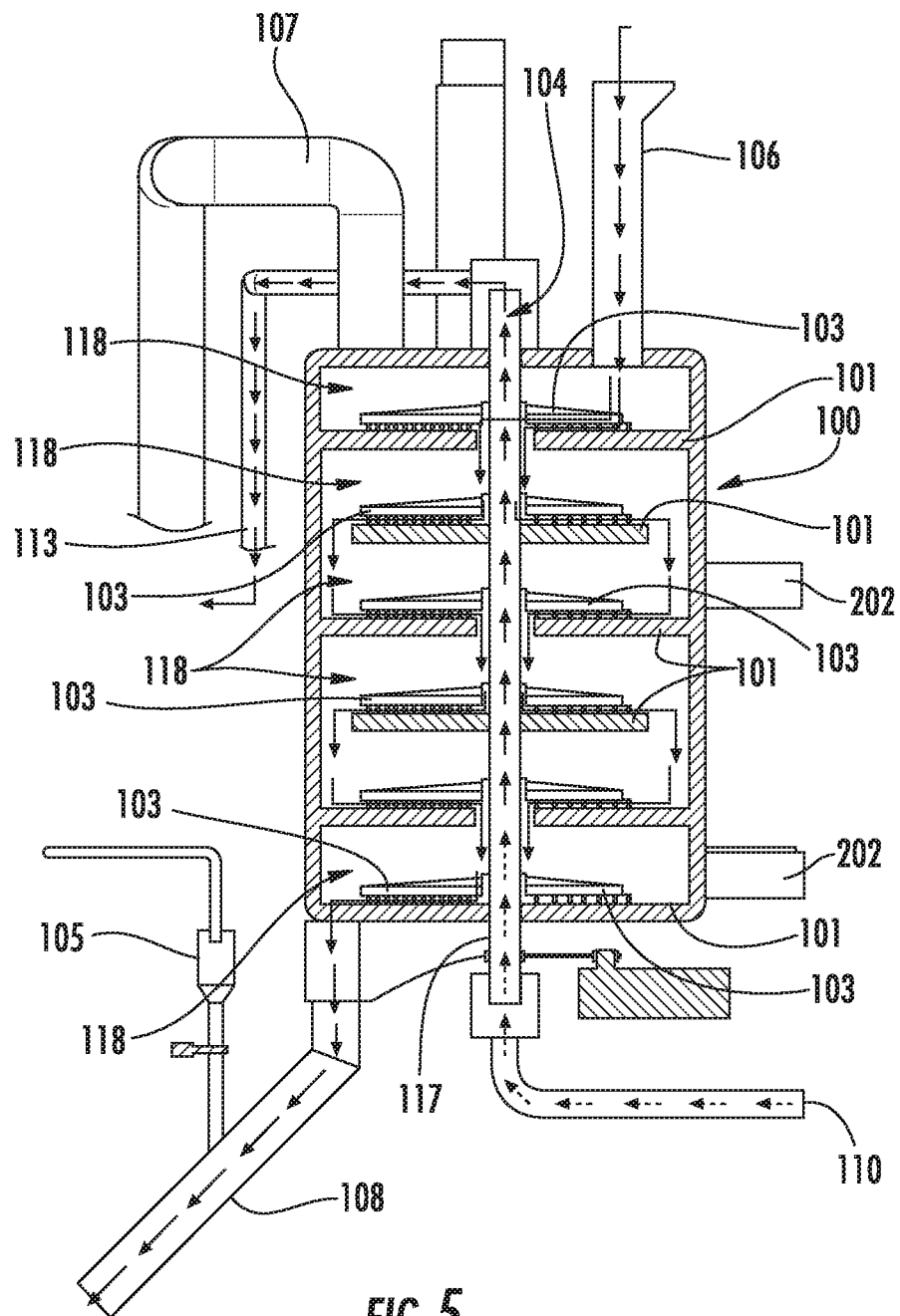
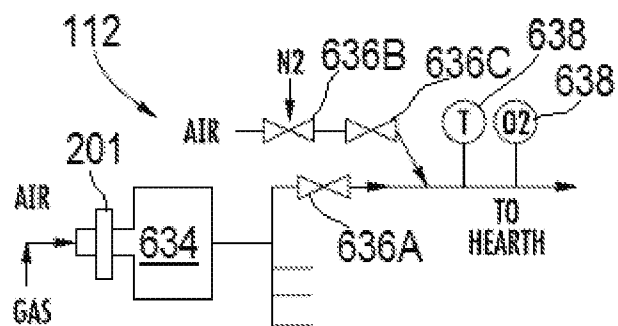
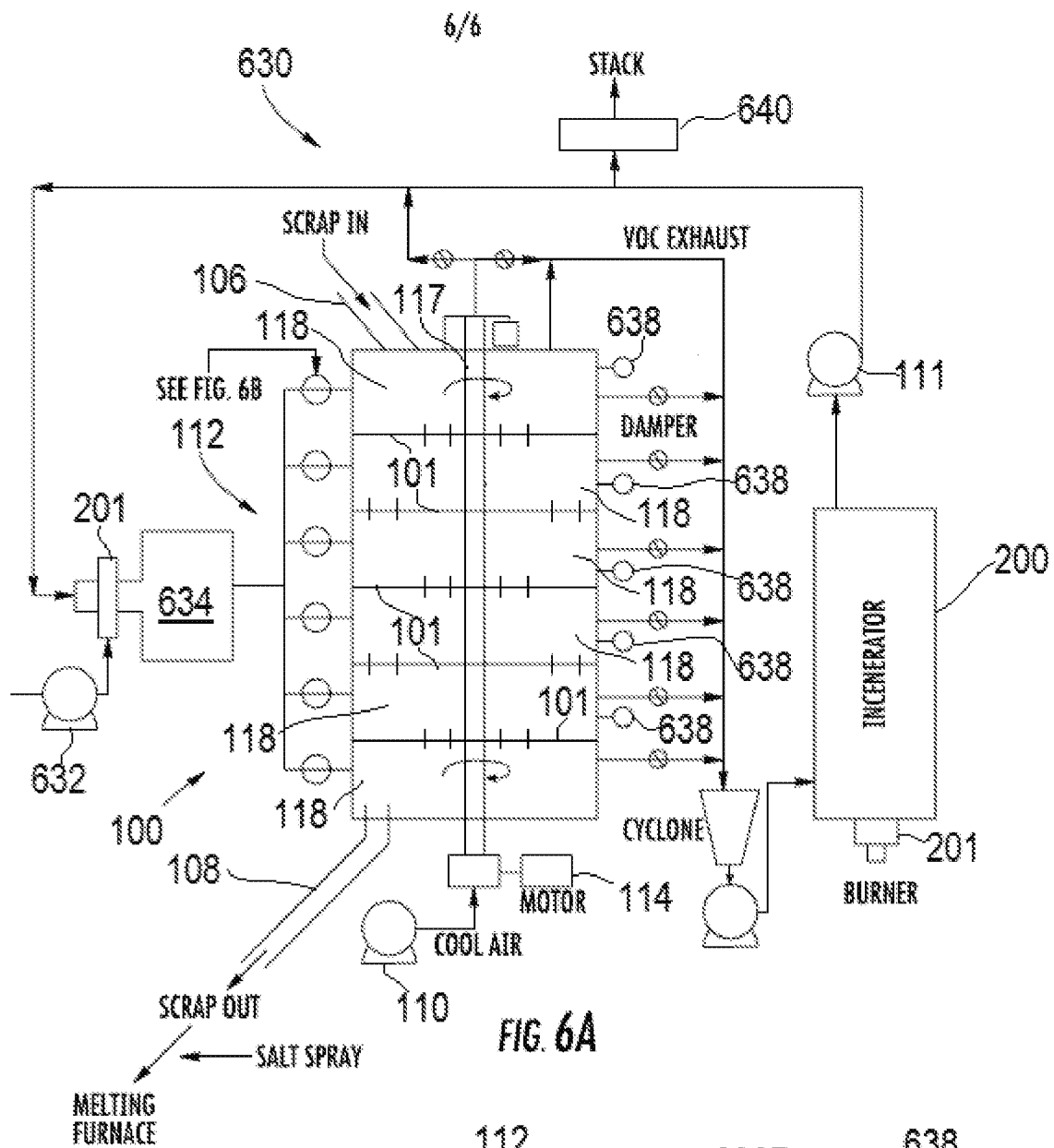


FIG. 3



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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/023741

A. CLASSIFICATION OF SUBJECT MATTER INV. F27B3/04 C22B1/00 F23G5/38 F27D17/00 F27D19/00 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) F23G F27B F27D C22B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 679 268 A (GURRIES RICHARD M [US] ET AL) 14 July 1987 (1987-07-14)	1,2,4-7, 10,11, 14-18
Y	figures 1a, 1b column 1, line 8 - column 18 column 2, line 34 - column 57 column 4, line 35 - column 7, line 51 -----	3,8,9, 12,13
X	US 2011/197797 A1 (BARRY LOUIS T [US] ET AL) 18 August 2011 (2011-08-18)	1,10
A	figures 1, 4, 5 paragraph [0001] paragraph [0009] - paragraph [0013] paragraph [0027] - paragraph [0043] ----- -/--	2-9, 11-18
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search	Date of mailing of the international search report	
24 May 2016	01/06/2016	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Jung, Régis	

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/023741

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 5 957 064 A (BARRY LOUIS T [US] ET AL) 28 September 1999 (1999-09-28) figure 4 column 1, line 5 - line 10 column 4, line 33 - column 6, line 36 -----	8,9,13 1-7, 10-12, 14-18
Y A	US 5 018 458 A (MCINTYRE GLOVER C [CA] ET AL) 28 May 1991 (1991-05-28) figures 1, 2 column 1, line 5 - line 10 column 1, line 57 - column 4, line 58 -----	3,12 1,2, 4-11, 13-18

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/023741

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4679268	A	14-07-1987	NONE
US 2011197797	A1	18-08-2011	NONE
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