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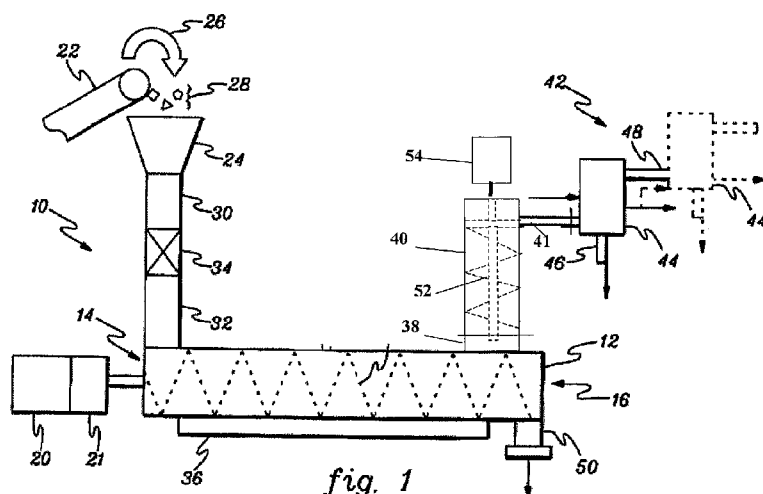
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(54) Title: METHODS AND APPARATUS FOR PYROLYZING MATERIAL



(57) Abstract: Methods and systems (10) for substantially continuously treating comminuted material (28) containing carbon and hydrogen, for example, used tires, are provided. The methods include the steps of introducing the tire material to an elongated chamber (12), transferring the tire material through the elongated chamber, heating the tire material to a temperature sufficient to pyrolyze the material to produce a gaseous stream; discharging the gaseous stream from the chamber, and cooling at least some of the gaseous stream to liquefy components of the stream. The transfer may be effected by a flexible, center-less screw conveyor (18) to minimize material buildup in the vessel. The cooling of the gaseous stream may be practiced by reverse condensation. The apparatus may further comprise an agitator (52) positioned in a conduit (40) operatively connected to an outlet (38) from the chamber (12), the agitator adapted to displace any condensate formed in the conduit (40).

METHODS AND APPARATUS FOR PYROLYZING MATERIAL

BACKGROUND

Field of the invention

[0001] The present invention relates to the processing of materials having organic components, such as, used tires, to recover usable hydrocarbons, such as fuels, and/or metals. In particular, aspects of the present invention include processes for treating used tires to recover usable fuels.

Description of Related Art

[0002] Used tires can pose significant environmental problems attendant to piles of discarded tires and also can create fire hazards. In the United States, nearly 300 million tires are discarded each year in addition to the estimated one billion scrap tires that are already in some form of storage. These numbers are according to the United States Environmental Protection Agency.

[0003] Tires are highly engineered materials and are generally composed of rubber, carbon black, steel, fabric, sulfur, and additives, among other components. Styrene-butadiene rubber is most commonly used in the manufacture of automobile and truck tires. Various carbon blacks are used in tires to strengthen the rubber and improve the resistance of the rubber to abrasion. In addition to used tires, a large amount of commodity plastics or polymers are discarded each year. Although collection and recycling of common waste polymers is more prevalent today, still a large portion of these materials is still discarded because of the cost of recycling and only limited technologies are available to sustain economically viable recycling.

[0004] A substantial effort has been directed toward finding uses for used tires, including potential uses as fuel in various kilns and boilers and in rubber product applications. Techniques have also been studied to recover material values (as opposed to destructive burning), but these techniques have been largely unsuccessful for technical or economic reasons.

[0005] One known technology, pyrolysis, which as been described as suitable for addressing these discarded materials, involves the use of high-temperature, thermal degradation of the material in tires and other materials, in the absence of oxygen. This process is typically referred to as “pyrolysis.” Pyrolysis can (depending upon the technology and conditions employed) convert feed materials, such as, used tires and other materials containing carbon, hydrogen and oxygen, into liquid hydrocarbon fuels; gaseous materials, for example, mixtures of CO and H₂ commonly referred to as synthesis gas or simply “syngas”; and elemental carbon (C) of varying quality. Each of these resultant materials can be valuable products. However, because pyrolysis technology and conditions prevalent heretofore, typically, instead of producing quality products, the results of prior art pyrolysis processing have commonly been the production of low value hydrocarbons, poor quality syngas, and low activity carbon black, among other things. It is not evident that any tire pyrolysis has been in commercial operation for sustained periods economically producing commercial quality syngas or carbon blacks. Though some of those attempts appear to have been technically possible and/or may have been successful in pilot scale demonstrations, the technologies used did not allow for appropriate up-scaling or commercialization of the process because of the difficulty in reliably processing the material in an economical manner.

[0006] The prior art discloses many types of pyrolyzing devices, chambers, vessels, or “retorts” for treating coal, shale, cellulose, and tires to recover or produce usable substances. (In the art, a “retort” may be any vessel in which substances are heated to produce a gaseous product.) Many of these vessels typically include a screw-type conveyor for transferring the material through the vessel during treatment. For example, the following prior art disclose pyrolysis chambers having screw conveyors for conveying and treating waste tires: U.S. Patent No. 4,084,521 of Herbold, et al.; U.S. Patent No. 4,235,676 of Chambers; U.S. Patent No. 5,389,691, of Cha, et al.; U.S. Patent No. 5,720, 232 of Meador; U.S. Patent No. 6,736,940 of Masemore, et al. U.S. Patent No. 7,101 of Weinke, et al. However, none of these “tire-treating” disclosures include a flexible, center-less screw, or a gas outlet agitator, or a reverse condensation recovery treatment of the gases as disclosed according to aspects of the present invention.

[0007] Though not explicitly disclosing a tire pyrolysis process, the following uncovered references disclose various devices for pyrolyzing various materials in a chamber having a screw conveyor: U.S. Patent No. 3,787,292 of Keappler; U.S. Patent No. 4,261,795 of Reilly; U.S. Patent No. 4,347, 119 of Thomas; U.S. Patent No. 4,501, 644 of Thomas; U.S. Patent No. 5,198,018 of Agarwal; U.S. Patent No. 5,411,714 of Wu, et al.; U.S. Patent No. 5,523,060, of Hogan; U.S. Patent No. 5,589,599 of McMullen, et al. U.S. Patent No. 6,226,889 of Aulbaugh, et al. [herein “Aulbaugh”] U.S. Patent No. 6,398,825 of Siniakkevitch, et al.; and U.S. Patent No. 6,758,150 of Ballantine, et al. However, none of these non-tire-related disclosures include a flexible, center-less screw, or a gas discharge agitator, or a reverse condensation recovery treatment of the gases. Note that though Aulbaugh discloses some form of center-less “auger,” contrary to aspects of the present invention, the Aulbaugh screw does not convey material through the pyrolysis chamber; as explained in the passage from column 10, line 55 to column 12, line 14, the auger 45/47 is part of an “airlock 40” through which material can be introduced or removed from the pyrolysis chamber.

[0008] U.S. Patent No. 4,056,461 of Unverferth [herein, “Unverferth”] appears to disclose a center-less screw in a retort chamber in Figure 1. However, Unverferth does not disclose treating tires: Unverferth treats shale. Moreover, unlike the screw conveyor of the present invention, the Unverferth screw would be unsuitable for handling tires and the soft, gummy intermediate pyrolysis products that characterize the treatment of tires. For instance, the clearance between the vessel of Unverferth and the screw of Unverferth is not effective in transferring tire material. In addition, the round bar stock from which conveyor 24 of Unverferth is made is clearly circular in cross section, and would provide little or no scraping function as desired by the invention. According to aspects of the invention, the inventors have found the sharp edges of the rectangular or square cross section overcomes the disadvantages of prior art screws, such as that shown in Unverferth.

[0009] U.S. Patent 7,329,329, of Masemore, et al. (published as pending application US 2004/0182001) [herein “Masemore”] is typical of the prior art having disadvantages that are overcome by aspects of the present invention. For example,

contrary to aspects of the present invention, Masemore includes a screw conveying device mounted at both ends of the pyrolysis chamber and having a central pipe or bar that rigidly supports the screw flights. As the present inventors have found, such a rigid construction is prone to failure due to the binding of the screw with the typically viscous byproducts of tire pyrolysis. The screw conveyor of the present invention overcomes this disadvantage.

[0010] In addition, prior art devices, such as, that described by Masemore, are also prone to failure due to plugging the gaseous hydrocarbon venting conduits. As the inventors have found through repeated experimentation and testing, the decrease in temperature that is inherent when venting gaseous pyrolysis products promotes condensation of the pyrolysis products and plugging of the venting conduits. Moreover, this plugging is exacerbated by providing numerous narrow conduits to vent gases that are prone to condense within the conduits. According to aspects of the invention, the gas discharge or venting conduits are minimized whereby the resulting venting conduit may have a larger diameter, and an agitating device is provided to prevent the build up of condensation products within the gas vent conduits. In addition, the use of a single gas venting conduit enhances the thermal efficiency of the processing according to aspects of the present invention.

[0011] In view of the foregoing, a desirable process would be capable of processing used tires and other material containing carbon, hydrogen, and oxygen to yield commercial hydrocarbon products and other valuable materials. Such a process would also desirably recover commercial-quality steel and commercial-quality carbon, for example, as commercial-quality carbon black, from the feedstock principally comprised, for example, of used tire rubber.

[0012] Aspects of the present invention are directed to a pyrolytic conversion process and a pyrolytic conversion apparatus that address the aforementioned needs and provide a commercially viable apparatus and methods for substantially continuously converting such materials into useful hydrocarbons and other usable materials.

BRIEF SUMMARY OF ASPECTS OF THE INVENTION

[0013] Aspects of the present invention provide methods and apparatus for substantially continuously treating feed materials containing compounds to produce usable liquid hydrocarbons, such as fuel oil, and other usable products. One aspect of the invention is an apparatus for pyrolyzing feed materials containing compounds containing carbon, hydrogen, and oxygen material, such as, comminuted tire material, the apparatus including: an elongated pyrolysis chamber having an inner surface and one or more inlets for introducing the comminuted tire materials; a conveyor for continuously conveying the comminuted tire materials and pyrolysis products thereof through the pyrolysis chamber while substantially simultaneously removing build-up of the tire material and the pyrolysis products from the inner surface of the pyrolysis chamber; means for maintaining a temperature within the pyrolysis chamber at a level sufficiently high to pyrolyze at least some of the feed material to gaseous hydrocarbons; and an outlet from the pyrolysis chamber for discharging the gaseous hydrocarbons; wherein the apparatus further comprises an agitator positioned in a conduit operatively connected to the outlet for discharging gaseous hydrocarbons, the agitator adapted to displace any condensate formed in the conduit, for example, a screw, an auger, a plunger, or a scraper. In one aspect, the conveyor comprises a helical, center-less screw mounted for rotation at a first end within the pyrolysis chamber and having an unsupported second end, the helical center-less screw comprising a helical bar having a rectangular cross section providing a surface adapted to displace build-up of tire material and pyrolysis products from the inner surface of the pyrolysis chamber.

[0014] These and other aspects, features, and advantages of this invention will become apparent from the following detailed description of the various aspects of the invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The subject matter, which is regarded as the invention, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other objects, features, and advantages of the invention will be readily

understood from the following detailed description of aspects of the invention taken in conjunction with the accompanying drawings in which:

[0016] FIGURE 1 is a schematic illustration of a process and apparatus of the present invention.

[0017] FIGURE 2 is a schematic illustration of another aspect of the invention.

DETAILED DESCRIPTION OF ASPECTS OF THE INVENTION

[0018] Aspects of the present invention comprise apparatus and processes for treating feed materials, for example, feed materials containing carbon, hydrogen, and oxygen compounds to produce usable hydrocarbon materials and other substances. In one preferred aspect, the feed material may be used tires, that is, used automobile and truck tires, although a wide variety of other feed materials containing compounds containing carbon, hydrogen, and oxygen material may be used in addition to or in lieu of used tires. Used tires are preferred because of their composition (particularly the recoverable components thereof), cost (used tires are frequently obtainable at a no cost or for a nominal fee, other than costs of transportation and handling) and the environmental mandates against improper disposal. However, other material such as plastics, polymers, rubbers, and other organic/petroleum-based materials are also suitable. In some instances, even when processing the preferred feeds (that is, used tires), it may be desirable to co-feed in various materials, for example, materials higher in carbon and/or hydrogen content than tires to adjust the quality of the syngas or hydrocarbon products being produced, such as, fuel oils or petroleum coke.

[0019] The feed materials may be in various physical forms and sizes, however, when processing used tires, it is preferable that the tires have been shredded to a size of less than about 2 inch “chucks,” for example, by processing the tires with one or more commercially available shredders, prior to being fed into the pyrolysis chamber. Used tires are commonly also shredded and sized to what is known as “crumb,” from which the metal content may have been removed, and may also be used as feed material. However, “chunks” of material are equally or more suitable in the practice of aspects of the invention, since these materials are commonly less expensive and

typically still contain the metal components of the tire, which can be beneficially recovered.

[0020] Preferably, in one aspect, the feed material should be free or relatively free of most inorganic materials (for example, concrete, soil, refuse, etc.) which may minimize the quality of various products produced according to aspect of the invention (for example, the quality of the recovered carbon), but the presence of metals (for example, steel, which is a common component of most tires) may be generally desirable and can be recovered as a valuable product, as discussed hereinafter. If necessary or desirable, steel or other magnetic-sensitive material may be removed by commercially available magnetic separators before, during, or after processing according to aspects of the invention.

[0021] Depending upon the degree of inclusion of material other than carbon, hydrogen, and oxygen in the specific feeds, in one aspect of the invention, it may be desirable to separate out some components (for example, inorganics, such as concrete) from the feed material prior to feeding the material into the pyrolyzer. However, as mentioned above, metals can be economically desirable, and may be removed from the chamber during or after treatment (for example, for technical and/or economic reasons).

[0022] The use of catalysts (for example, AlCl_3), as described in some prior art literature as possibly assisting in the conversion of feed material, is not required for the practice of aspects of the invention, but may be introduced to the process, if desired.

[0023] In one aspect, the feed materials are fed into an elongated pyrolysis chamber in a manner designed to limit the introduction of air, since air (which is principally oxygen and nitrogen), may adversely affect the quality of the syngas or gaseous hydrocarbons produced. In one aspect, a double air lock is used at the point of feed introduction to minimize or prevent the introduction of air. An air lock may also be used at the exit of the chamber.

[0024] A schematic illustration of a process and an apparatus 10 according to one aspect of the present invention is shown in FIGURE 1. Apparatus 10 includes a

cylindrical treatment vessel, retort, or “pyrolyser” 12 having a first end 14 and a second end 16 containing a conveyor 18, for example, a screw conveyor, adapted to transfer comminuted material from first end 14 to second end 16. Conveyor 18 is driven by a motor 20, or other source of motive force, as is conventional, via speed reducer 21.

[0025] In the following discussion and in the subsequent claims, the material treated in aspects of the invention is referred to as “comminuted” material. The term comminuted is meant to imply any material that is provided as particles or pieces, but is not intended to limit the size or shape of the material provided. The size of the material may vary from micron scale and smaller to centimeter scale or larger. In one aspect, the size of the material treated may be limited to a size that can effectively be treated in vessel 12 while providing little or no untreated material in the resulting product. The comminuted material treated in vessel 12 may include any material containing carbon and hydrogen that when heated in an atmosphere having little or no oxygen produces gaseous hydrocarbons and carbon-containing solids. It is contemplated that the material treated in vessel 12 comprise any petroleum-based material, for example, elastomers or plastics, for example, recycled plastics and the like. One source of feed material that may be provided are rubber tires, for example, scrap tires, comminuted by conventional shredding devices or grinders to provide tire particles or “crumb” rubber tire pieces.

[0026] As discussed above, since tires are engineered materials containing an array of materials and additives, it is likely that comminuted tire material include metal and fabric belts that may also be introduced to apparatus 10. These materials may be isolated if desired. For example, the ferromagnetic content of the tires may be isolated by one or more conventional magnets. However, in aspects of the invention, apparatus 10 is tolerant of such material and no separation or isolation of material may be necessary.

[0027] Regardless of the source and size of the comminuted material, the material may typically be introduced to system 10 by a conveyor 22. Conveyor 22 may be any conventional conveyor, for example, a belt conveyor having material transferring ridges or projections. Conveyor 22 may introduce the comminuted material to an

open hopper 24 as indicated by arrow 26. The comminuted material is generally indicated by comminuted material pieces 28 in FIGURE 1. Hopper 24 directs the material 28 through one or more conduits 30 and 32 and introduces material 28 to first end 14 of conveyor 12. In order to minimize the air introduced to vessel 12, specifically, oxygen and nitrogen, one or more isolation devices 34 are typically provided in conduits 30 and 32. Isolation device 34 may be any device that limits the content of oxygen and nitrogen introduced to vessel 12 while permitting the passage of material 28, for example, device 34 may comprise one or more valves.

[0028] The feed mechanism that introduces material 28 to apparatus 10 may also preferably ensure that substantially all of the air contained in the waste is extracted, for example, using commercially available isolation devices, such as, auger extruder feeders or ram feeders. In addition to the above-described aspects of feed introduction, it is to be understood that other conventional aspects of feed preparation (for example, screening, sorting, or drying) may be provided before or during transferring material 28 to apparatus 10.

[0029] In one aspect, the inventors have found that isolation device 34 may comprise at least two flapper-type valves, for example, flapper valves provided by the Plattco Corporation, or their equivalent. In one aspect, at least two flapper valves are provided, one positioned above the other, and a void space is provide between the two flapper valves. This void space may be purged with a non-oxygen gas, for example, carbon dioxide or an inert gas, such as argon or helium. The timing of the opening and closing of the two flapper valves may be provided whereby the upper valve is open and the lower valve closed whereby material 28 is allowed to fill the void space between the two valves. The upper valve is then closed while the lower valve remains closed while the space is purged with the purge gas. After purging, the lower valve is opened to transfer the material with little or no oxygen to vessel 12.

[0030] In another aspect, the isolation device 34 may be a star-type feeder having a rotor having a plurality of pockets that receive and discharge material 28 to vessel 12. A pocket of the star-type feeder may also be purged with an inert gas to minimize the oxygen introduced to the vessel 12. In another aspect, an extrusion-type feeder may

also be used where the material 28 is forced through a restriction whereby little or no air is introduced to vessel 12.

[0031] Vessel or chamber 12, which may also be referred to as a “pyrolyzer,” a “treatment vessel,” a “retort,” or a “reactor” 12, used in the practice of aspects of the present invention is preferably an elongated pyrolysis chamber in the form of a cylindrical reactor. Vessel 12 may be horizontally positioned or oriented or may have a slight upward pitch or downward pitch. Although a U-shaped or other shaped reactor could be used, the vessel 12 may typically be a straight, horizontally positioned cylinder, free of any significant bends or curves. The cylindrical reactor 12 may be constructed of steel, for example, stainless steel, although other materials of sufficient structural integrity and thermal properties would also be suitable. In one aspect, reactor 12 is a horizontally positioned, cylindrical reactor having an internal diameter (ID) of about 12 inches to about 16 inches that may be used for optimal heat transfer and efficiency, with the cylindrical reactor having a length of between about 30 feet and about 40 feet. If higher feed rates are desired, using two or more reactors in parallel, would be preferable (for example, to help ensure uniform heat transfer and processing) as opposed to increasing the size of a single reactor. One or more reactors may be used, for example, two reactor vessels in parallel may be used.

[0032] Vessel 12 may typically be a cylindrical vessel, for example, a generally circular cylindrical vessel, though vessel 12 may also comprise a u-shaped trough. In one aspect, when vessel 12 is circular cylindrical, it may have an inside diameter ranging from about 6 inches to about 4 feet, but may typically be about 8 to about 18 inches inside diameter, for example about 12 inches in inside diameter. Again, vessel 12 may be made from any conventional structural material capable of handling the operating temperatures, for example, steel, aluminum, or titanium, but is typically made from stainless steel, for example, 304 or 304L stainless steel. The length of vessel 12 may vary from about 6 feet to 200 feet, but is typically about 25 to 50 feet in length, for example, about 30 feet in length. Vessel 12 may be operated under vacuum or at an overpressure, that is, a pressure above atmospheric pressure. Vessel 12 may typically be substantially horizontal or, in one aspect, may be directed at an angle to the horizontal, for example, an upward angle. In this aspect of the invention,

the upward angle or inclination of vessel 12 promotes the flow of gaseous hydrocarbons produced toward the second end 16 of vessel 12.

[0033] After material 28 is introduced to vessel 12, material 28 is transferred from first end 14 to second end 16 by conveyor 18 driven by motor 20 and gear reducer 21. In one aspect, conveyor 18 may typically be supported at only a first end, that is, an end of conveyor 18 operatively driven by motor 20, and have a second free end opposite the first end. According to aspects of the invention, the second free end may be free to flex or deflect, for example, flex or deflect as the material loading on conveyor 18 varies, for example, varies along the length of chamber 12 or about the inside diameter of chamber 12. The horsepower of motor 20 may vary depending upon the size of conveyor 18 and the nature of material 28 being transferred. Typically, motor 20 may have a horsepower of at least about 5 Hp to about 50 Hp. Reducer 21 may be chosen whereby conveyor 18 is rotated from about 0.25 rpm to about 10 rpm depending upon the nature of material 28 and the desired treatment time and temperature. For example, when treating comminuted tire material, conveyor 18 may be driven at about 1 rpm. Conveyor 18 may comprise any type of conveyor adapted to transfer comminuted material, for example, a screw conveyor, a drag chain conveyor, a belt conveyor, and the like. In one aspect of the invention, conveyor 18 comprises a screw conveyor. Conveyor 18 may have a constant or variable flight pitch. For example, the pitch of the flights of conveyor 18 may be varied to vary the residence time in different sections of vessel 12 during treatment.

[0034] As shown in FIGURE 1, reactor chamber 12 includes a rotating helical conveyor 18, for example, a center-less screw or coil conveyor extending along the chamber 12. The helical center-less screw or coil conveyor 18 typically includes a helical screw having multiple flights or coil loops, a first end mounted to drive plate and a second free end opposite first end. In one aspect, flights or loops may be appropriately sized to provide a close tolerance between the flights or loops and the interior surface of the walls of the chamber 12 whereby material 28 and any pyrolysis produces are continuously conveyed through chamber 12. In one aspect, the center-less conveyor 18 having screw or coil is significantly different in design and function from conventional auger-type feeders or other conveyors, which typically include a

shaft around which flights, blades, or other components turn to convey material in a conduit. For example, according to aspects of the invention, since uniform heating of material is preferred to provide optimal product formation without undue charring, the present invention desirably provides a conveying means with no shaft, or other hot spots, upon which the undesirable formation and buildup of components can occur. Further, the close clearance (typically less than 1 inch) between the outermost extension of the flights or coils and the interior surface of the walls of chamber 12 results in removal of any build-up of feedstock and/or pyrolysis products from the interior walls of the chamber 12.

[0035] In one aspect, the flights or coils of conveyor 18 may be constructed from bar stock, for example, from 1-inch square 304 stainless steel bar stock. The use of bar stock can facilitate construction while providing the desired conveying function; however, in other aspects, flights or coils may be fabricated from elongated bar stock having a circular, a rectangular, or a triangular cross section, among other shapes. The coils or flights may be made of stainless steel, for example, 304 or 340L stainless steel, though other materials of sufficient strength/flexibility may be used. In one aspect, coils or flights may effectively convey material 28 and pyrolysis products through chamber 12 by providing at least some displacement or “scraping” of material from the inside surface of the walls of chamber 12, for example, to minimize or prevent the buildup of material on the inside surface of chamber 12 that may otherwise interfere with the proper operation of apparatus 10. In one aspect, the coils or flights of conveyor 18 may convey material along the inside surface of chamber 12 by flexibly deflecting from the reactor walls in a “slinky-like” fashion or movement due to the flexibility of the center-less conveyor. In contrast, prior art conveyors supported at both ends or made from unduly rigid bars are typically more susceptible to plugging or jamming with feed material, for example, as commonly occurs when conveying comminuted tire material with rigid auger-type screw conveyors. According to aspects of the present invention, the material of construction of the coils or flights have sufficient thermal and structural properties for the temperature and stress to which the coils or flights will be subject, but are also flexible and can deflect. The helical center-less screw conveyor are typically driven by motor 20 operatively connected to first end of conveyor 18 and unsupported at the second end, other than

by contact with the inside surface of chamber 12. Conveyor 18 may typically be rotated at a relatively slow speed, that is, at a low number of revolutions per minute (for example, about 1 RPM), to help ensure uniform mixing and heat transfer.

[0036] During transport of material 28 from first end 14 to second end 16, the material 28 is heated to a temperature at which gaseous hydrocarbons are released. This temperature is typically at least about 400 degrees C, but may range from about 450 degrees C to about 650 degrees C. The processing temperature is dependent on the types of feed and the mix of products desired. For example, a temperature range of about 450 to about 475 degrees C (that is, about 842 to 887 degrees F) is typically optimal for processing a shredded tire feed, but if one wants to maximize the recovery of liquid hydrocarbon products, a somewhat lower temperature may be used; for more gaseous products, a somewhat higher temperature may be used.

[0037] This heating is typically provided by heating device 36 shown in FIGURE 1. Heating device 36 may comprise any conventional heating device adapted to heat at least a portion of vessel 12 and its contents. Heating device 36 may be resistive heating device, for example, one or more electrical heating coils mounted to vessel 12. Heating device 36 may comprise an oil or gas heater having a fuel inlet and one or more fuel burners mounted to heat vessel 12. Heating device 36 may be adapted to burn one or more of the gaseous or liquid hydrocarbons produced by apparatus 10. Vessel 12 may be insulated by a suitable insulation material to minimize the loss of heat from vessel 12.

[0038] Heating device 36 may be a gas-fired heat exchanger, for example, a heat exchanger jacketing reactor chamber 12, but heating device 36 may also be one or more electrical heaters, though any other conventional heating means may be suitable for heating chamber 12 and its contents. In one aspect, a gas-fired heat exchanger may be used, since syngas or other gaseous hydrocarbons produced by the process of this invention may be recycled back to and used as all or part of the gas fed to the gas-fired heat exchanger. Since cooling and product recovery occurs at or toward the outlet or second end 16 of reactor chamber 12, the outlet or second end 16 of chamber 12 may not need to be heated.

[0039] According to aspects of the invention, the temperature and residence time within the pyrolysis chamber 12 may be maintained at levels sufficiently high to pyrolyze the feed material 28 to hydrogen and carbon containing gases, for example, to carbon monoxide (CO), hydrogen (H₂) and/or hydrocarbon gases, yet be at a sufficiently low temperature to avoid unduly charring the carbon compounds. For example, when processing used tires sized to about 2 inch chucks in a 12-inch stainless steel cylindrical reactor 12 about 32 feet in length, chamber 12 may electrically heated so that material 28 is heated to about 450 degrees C to about 475 degrees C with a residence time of about 30 to about 45 minutes. Under these conditions, the feed material 28 may be converted into a soft, gummy mass or soft, crumbly mass at about the midway point in the pyrolysis chamber 12 and may be sufficiently fluid to facilitate further processing in the chamber 12 and the separation of “cuts” of recovered gaseous, liquid, or solid products. In other aspects, the feed material 28 may be converted into a viscous, syrupy fluid at about the midway point in the pyrolysis chamber or near the first end 14 of the chamber 12. According to aspects of the invention, by using more efficient gas-fired heaters, a shorter residence time in chamber 12 can be provided.

[0040] The gaseous hydrocarbons released by the heating of material 28 in an atmosphere having little or no oxygen, that is, by pyrolysis, will vary depending upon the nature of the material 28 being processed. The gases released during pyrolysis exit vessel 12 via one or more discharge nozzles 38, see FIGURE 1, and are passed through one or more conduits 40 to a condenser system 42. Examination of the gases released during the treatment of tires in vessel 12 according to aspects of the invention shows that these gases comprise a range of non-condensable gases, gaseous hydrocarbons, and volatile sulfur compounds (VSC), among other gases. Table 1 identifies one set of typical species of gases produced during the processing of tires. It is understood that the species identified in Table 1 are one set of gas species that can be generated according to aspects of the invention, and the actual gas species generated will vary depending upon the nature of the feed material and the treatment conditions.

Table 1

Typical Chemical Analysis of Gases Produced According to Aspects of the Invention

<u>Non-Condensable Gases</u>		<u>Hydrocarbons</u>		<u>Volatile Sulfur Compounds</u>	
Gas	Volume %	Gas	Volume %	Gas	Parts per mill. (ppm)
Nitrogen	0.33	Ethylene	8.26	Hydrogen Sulfide	577
Oxygen	Non detect.	Ethane	8.34	Carbonyl Sulfide	437
CO ₂	10.5	Propylene	6.24	Sulfur Dioxide	Non detect.
CO	2.56	Propane	4.17	Methyl Mercaptan	217
Hydrogen	10.1	Isobutane	9.76	Ethyl Mercaptan	192
Argon	Non detect.	n-Butane	3.15	Dimethyl Sulfide	10
Methane	22.1	Butene	2.42	Carbon Disulfide	98
		Isopentane	2.04	Isopropyl Mecapt.	14
		n-Pentane	6.33	t-Butyl Mercapt.	3.0
		Pentene	1.42	n-Propyl Mercapt.	4.4
		Hexane	2.26	Methyl Ethyl Sulf.	4.2
				Thiophene.	321
				Isobutyl Mercapt.	0.5
				Dimethyl Disulfide	5.6
				Others	230

[0041] Condenser system 42 is adapted to cool at least some of the gaseous species released from vessel 12 to produce at least one liquid hydrocarbon, for example, one or more oils of varying weights. The cooling in condenser system 42 may be effected in one or more heat exchangers 44 adapted to receive the gaseous hydrocarbons via one or more conduits 40 and a coolant, for example, water, via conduit 45. The coolant may be used repeatedly and recirculated through the two or more heat exchangers 44. The circulation of coolant through two or more heat exchangers may be practiced in a counter-current fashion, that is, with the coolest coolant cooling the coolest gaseous hydrocarbons, or in a co-current fashion, that is, with the coolest coolant cooling the hottest gaseous hydrocarbons. The condensed liquid hydrocarbon, for example, an oil, may be discharged from outlet conduit 46 and forwarded to further processing, for example, filtering, storage, or for a source of fuel for heating device 36. The non-condensed gaseous hydrocarbon, for example, methane, ethane, or propane, may be discharged from condenser system 42 via conduit 48. In one aspect of the invention, condenser system 42 may include one or more separation devices, for example, settling tanks, cyclone separators, or baffles, designed to isolate entrained solids, for example, carbon black, tramp material, ash, and the like, prior to introducing the gaseous stream to the condenser vessels.

[0042] According to one aspect of the invention, condenser system 42 is adapted to a perform “reverse condensation” of the gaseous hydrocarbons discharged from nozzles 38. According to this aspect, the gaseous hydrocarbon stream is sequentially condensed to a first liquid hydrocarbon fraction, for example, an oil, and then a second liquid hydrocarbon fraction of lower weight than the first liquid hydrocarbon fraction. For example, the first liquid hydrocarbon fraction may be a fuel grade oil and the second liquid hydrocarbon fraction may be kerosene-grade oil or a gasoline-type liquid hydrocarbon. In one aspect, at least three or four heat exchangers 44 are provided in condenser system 42 whereby at least three or four liquid hydrocarbon fractions are provided.

[0043] Table 2 identifies the results of the chemical analysis of four liquid samples produced by means of condensing the gases discharged from vessel 12. As shown, the liquids, typically, hydrocarbons, are primarily carbon and hydrogen, but nitrogen

and sulfur are also present. Though not indicated in Table 2, Gas Chromatograph/Mass spectrometer analysis of fluid samples produced by aspects of the invention reveal that a broad spectrum of hydrocarbons are produced by aspects of the invention.

<u>Table 2</u> Typical Chemical Analysis of Hydrocarbon Liquids Produced According to Aspects of the Invention, Weight Percent				
<u>Constituent</u>	<u>Sample #1</u>	<u>Sample #2</u>	<u>Sample #3</u>	<u>Sample #4</u>
Sulfur	0.90	0.91	0.75	0.73
Ash	0.05	0.02	0.01	0.03
Carbon (Total)	89.6	88.86	85.43	87.01
Hydrogen	9.71	10.00	10.08	10.94
Nitrogen	0.36	0.32	0.27	0.20
Specific Gravity	0.9524	0.9265	0.8850	0.8812
BTU Value [BTU/lb]	17868.90	17518.60	15194.60	15429.80

[0044] The non-volatile material, for example, carbon black, steel, and other inorganic material that remains in the vessel 12 after the volatile compounds have been driven off are discharged from outlet 50, see FIGURE 1. These materials may be forwarded to further processing, for example, screening, metal removal, or to storage for latter use or recycling. Table 3 lists the results of chemical analysis of the typical constituents of solids removed from vessel 12 according to aspects of the invention. As indicated, the solids produced are primarily carbon.

<u>Table 3</u> Typical Chemical Analysis of Solids Produced According to One Aspect of the Invention	
<u>Constituent</u>	<u>Composition (%)</u>
Carbon	82.73
Hydrogen	2.36
Nitrogen	0.31
Sulfur	2.85
Ash	11.31
Oxygen	0.44
Moisture	0.80
Total	~100
Dulong BTU Value	13,666.38 BTU-lb

[0045] According to aspects of the invention, the feed rate of material 28 through chamber 12 may be dependent upon several factors, including the diameter of reactor chamber 12 and the physical form and composition of feed material 28. In one aspect, the feed rate may be selected to optimize the uniform heating of material 28 and the uniform production of the desired pyrolysis products during processing. For example, when processing 2 inch chunks of used tires in as 12-inch diameter stainless steel cylindrical reactor chamber 12 described above, a processing rate of about one tire, for example, about 20 pounds, per minute may be provided.

[0046] The processing in chamber 12 may be practiced at various pressures. For example, maintaining a slight positive or over pressure in the reactor may be beneficial in embodiments in which production of gaseous hydrocarbons is sought to

be maximized. Alternately, reactor 12 may be operated under vacuum, for example, to minimize potential safety issues.

[0047] In one aspect, reactor chamber 12 can be provided with multiple treatment zones, for example, at least three (3) treatment zones may be provided. For example, a heating zone, a cooling zone, and a recovery zone. The discussion of heating in the foregoing sections may apply to the what might be called the heating zone. However, in one aspect, the control of temperature (including by providing cooling fluid, such as, water) may be provided near or at the second end 16 or outlet of the chamber 12. Controlling the temperature of the second end 16 or outlet of chamber 12 may facilitate recovery of gaseous hydrocarbons. These gaseous hydrocarbons may be further treated as necessary or desirable. Additional processing to treat particulate and impurities in the syngas or hydrocarbon gas (for example, using plasma arc technology) may be employed as necessary or desirable depending on the desired quality of the gaseous hydrocarbons or syngas produced. In one aspect, at least some oxygen may be introduced to the process chamber 12 at one or more predetermined locations in order to promote the conversion of elemental carbon (C) to carbon monoxide (CO) or carbon dioxide (CO₂), though CO generation may be undesirable due to its low heating value.

[0048] According to one aspect of the invention, when the processed feed material 28 is used tires, carbon and metal fractions may be produced by the process practiced in chamber 12. The carbon produced, for example, as characterized in Table 3 may be suitable for use as a coal substitute for heating or other processing. The metal fractions produced, for example, iron or steel, may comprise a high grade of steel that can be recycled.

[0049] In one aspect, conveyor 18 may comprise a “center-less screw,” that is, a screw conveyor having no central shaft as is typically of screw conveyors. According to aspects of the invention, conveyor 18 conveys feed material 28 and any products of pyrolysis through vessel 12 from first end 14 to second end 16. For example, in one aspect, conveyor 18 may comprise a scraping device having at least one flight that bears against the inside surface of vessel 12. In one aspect, conveyor 18 is mounted at first end 14 vessel 12, but is unsupported at free second end, other than be contact

with the inside surface of vessel 12. In one aspect, screw conveyor 18 is flexible and unsupported at its second end whereby the position of screw conveyor 18 in vessel 12 may vary depending upon the loading on screw conveyor 18. For example, in one aspect, the flexibility of center-less screw conveyor 18 permits screw to flex under load and, for instance, deflect when contacting material that would obstruct or prevent the rotation of a non-flexible screw conveyor. In one aspect, the flexible, center-less screw conveyor 18 having free end overcomes the disadvantages of conventional screw conveyors allowing the pyrolytic treatment disclosed herein possible. In another aspect, center-less screw may be supported, for example, at end its second end or anywhere between its first end and second end, while still having sufficient flexibility to perform the desired transfer function. Conveyor 18 may be made from any metallic material, for example, steel, stainless steel, aluminum, or titanium, but is typically made from 304 stainless steel. In one aspect, conveyor 18 may be made from coiled 1-inch square 304 stainless bar.

[0050] As shown in FIGURE 1, outlet 38 from vessel 12 for venting gaseous products of pyrolyzation may be the only outlet of gaseous by products, or may one of a plurality of outlets positioned furthest away from first end 14. According to one aspect, and in contrast to prior art teachings, one or more outlets 38 are positioned distal first end 14 to provide the most efficient use of the heat used to pyrolyze the material. For example, by limiting removal of gaseous by-products to the later stages of treatment, less heat is removed from the process, for example, in comparison to prior art systems having gaseous discharges distributed along the length of vessel 12.

[0051] The present inventors have also found that limiting the number of gaseous discharges 38 also reduces or eliminates the potential to plug gaseous discharge outlets and downstream conduits. As the present inventors learned through experimentation and testing, the temperature gradient typically present between the heated pyrolysis chamber 12 and the gas processing system, for example, system 42, typically exposes the gaseous pyrolysis byproducts to a temperature that promotes condensation and solidification of the once gaseous materials. This condensation may typically build up upon the inner surfaces of transport conduits, for example, conduit 40, restricting gas flow, and eventually plugging the conduit completely. According

to one aspect, the inventors found that reducing the number of outlets 38, for example, from 3 or more to one, not only reduces the potential for condensation and plugging, but also permits the use of larger conduits that, though still prone to condensation, are less prone to plugage.

[0052] However, the inventors found that even with a single discharge 38, condensation and potential plugage may continue to hamper operation. In response to their experimental experience, the inventors have found that an agitation device 52 driven by, for example, motor and/or gear reducer, 54, positioned in a gas discharge conduit, for example, conduit 40, can be an effective way to minimize or prevent the plugging of gas discharge conduits by condensed and/or solidified gases. According to one aspect of the invention, the agitation device may be any device adapted to rotate and/or translate within conduit 40 and disrupt, remove, dislodge, or otherwise prevent the build up of condensed gases within the conduit. For example, agitation device 52 may be a screw, an auger, a plunging device, or a scraping device, among others. If a rotatable device, agitation device 2 may be rotated at relatively low speed, for example, 20 rpm or less, or 10 rpm or less.

[0053] In the aspect of the invention shown in FIGURE 1, agitation device 52 is positioned in a generally radially directed conduit 40, for example, substantially perpendicular to the direction of elongation of vessel 12. However, according to aspects of the invention, one or more agitation devices, similar to device 52, may be positioned in one or more conduits 40 and related or downstream conduits, such as conduit 41 shown in FIGURE 1. In addition, as shown by system 110 in FIGURE 2, according to another aspect, conduit 40 may not be perpendicular, but may be directed at a substantially oblique angle to the direction of elongation of vessel 12. In this aspect, agitation device 52 may be positioned at an oblique angle in conduit 40 and driven by motor/reduce 54. As shown, motor/reduce 54 may drive a shaft through vessel 44 in order to accommodate the geometry of system 110. The sizes of conduits 40 and 41 and the sizes of agitation device 52 may vary depending upon the size and throughput of systems 10 and 110. Other alternative arrangements for one or more agitating device 52 shown in FIGURES 1 and 2 can be provided as the conduit and vessel geometry and configuration dictates. Regardless of configuration, one or more

agitation devices 52 in one or more conduits 40 can minimize or prevent the plugging of gaseous conduits which plague the prior art.

Example of One Aspect of the Invention

[0054] An example of processing of used tires in accordance with one aspect of the present invention is as follows: Used tires which have been shredded to 2 inch chunks were fed at the rate of 20 pounds per minute into a inlet of an elongated cylindrical pyrolysis chamber (such as chamber 12) which is 32 feet long and 16 inches in internal diameter. The pyrolysis chamber has an electrical motor driven, rotatable helical center-less coil within it having flights that have been sized so as to provide a one-inch clearance between the flights and the interior walls of the pyrolysis chamber. The coil screw conveyor continuously conveys the feed material through the pyrolysis chamber while simultaneously removing build-up of feed material or the pyrolysis products thereof from the inner walls of the pyrolysis chamber. The pyrolysis chamber is heated by a gas-fired heat exchanger and the temperature in the pyrolyzer is maintained at about 450⁰C. The coil is rotated at 1 RPM and provides for a residence time of 30 to 45 minutes for the material in the pyrolyzer. This temperature and residence time is sufficiently high to pyrolyze the feed material to liquid and gaseous hydrocarbons, yet sufficiently low to avoid unduly converting carbon compounds to elemental carbon. The pyrolyzed material is principally made up of liquid and/or gaseous hydrocarbons, steel, carbon, and sulfur. The gaseous pyrolysis products are separated into component streams by cooling and other standard separation techniques. Approximately 504 lbs/hour of liquid hydrocarbon, 125 lb/hour of gaseous hydrocarbon were produced. The liquid-to-gas ratio of the hydrocarbon portion was about 4:1. The liquid hydrocarbon stream was further processed by distillation into gasoline, diesel, heating oil and other "cuts." The gaseous hydrocarbon stream has a BTU value comparable to natural gas and was recycled back to the pyrolyzer as fuel for the pyrolozer gas fired heater. The steel and carbon were cooled and collected as a mixture of solids (about 570 lbs/hour were produced). The steel was separated from the mixture by use of a magnetic separator.

[0055] While several aspects of the present invention have been described and depicted herein, alternative aspects may be effected by those skilled in the art to

accomplish the same objectives. Accordingly, it is intended by the appended claims to cover all such alternative aspects as fall within the true spirit and scope of the invention.

* * * * *

CLAIMS

1. An apparatus (10) for pyrolyzing comminuted tire materials, the apparatus comprising:

an elongated pyrolysis chamber (12) having an inner surface and one or more inlets (32) for introducing the comminuted tire materials (28) ;

a conveyor (18) for continuously conveying the comminuted tire materials and pyrolysis products thereof through the pyrolysis chamber while substantially simultaneously removing build-up of the tire material and the pyrolysis products from the inner surface of the pyrolysis chamber (12);

means (36) for maintaining a temperature within the pyrolysis chamber at a level sufficiently high to pyrolyze at least some of the feed material to gaseous hydrocarbons; and

an outlet (38) from the pyrolysis chamber for discharging the gaseous hydrocarbons;

wherein the apparatus further comprises an agitator (52) positioned in a conduit (40) operatively connected to the outlet (38) for discharging gaseous hydrocarbons, the agitator adapted to displace any condensate formed in the conduit (40).

2. The apparatus as recited in claim 1, wherein the agitator (52) is one of a screw, an auger, a plunger, and a scraper.

3. The apparatus as recited in claim 2, wherein the conduit (40) operatively connected to the outlet (38) comprises a radially directed conduit substantially perpendicular to a direction of elongation of the chamber.

4. The apparatus as recited in claim 2, wherein the conduit (40) operatively connected to the outlet (38) comprises an obliquely directed conduit substantially non-perpendicular to a direction of elongation of the chamber

5. The apparatus as recited in claim 1, wherein the conveyor (18) comprises a helical, center-less screw mounted for rotation at a first end within the pyrolysis chamber and having an unsupported second end, the helical center-less screw comprising a helical bar having a rectangular cross section providing a surface adapted to displace build-up of tire material and pyrolysis products from the inner surface of the pyrolysis chamber.

6. The apparatus as recited in claim 5, wherein the helical, center-less screw conveyor further comprises an initial portion comprising means for reducing a size of the feed material.

7. The apparatus as recited in claim 1, wherein the apparatus further comprises a heat exchanger (44) for cooling the gaseous hydrocarbons.

8. The apparatus as recited in claim 1, wherein the apparatus further comprises means for using at least some of the gaseous hydrocarbons produced for the means for maintaining the temperature.

9. The apparatus as recited in claim 1, wherein the apparatus further comprises a plurality of valves (34) associated with the one or more inlets (32) for introducing the comminuted tire materials for minimizing the introduction of air to the chamber.

10. The apparatus as recited in claim 1, wherein the apparatus further comprises a first heat exchanger (44) adapted to cool the gaseous hydrocarbons and condense a first liquid hydrocarbon from the gaseous hydrocarbons and a first cooler stream (48) of gaseous hydrocarbons; and

a second heat exchanger (44) adapted to cool the first cooler stream of gaseous hydrocarbons (48) to condense a second liquid hydrocarbon, different from the first liquid hydrocarbon, from the first cooler stream of gaseous hydrocarbons and a second cooler stream of gaseous hydrocarbons.

