MULTI-SHELF FURNACE FOR USE AT LOW TEMPERATURE

Object of the invention

[0001] The present invention relates to the technical field of industrial thermal reactors for the low-temperature transformation of solid or liquid material. Low temperature refers to a temperature suitable for the biomass torrefying method, typically below 300°-350°C.

[0002] It is more particularly intended for combustible biomass suppliers wishing to concentrate and stabilize their product before shipping, combustible biomass users wishing to replace coal with a green fuel, industrial sludge or purification station producers wishing to stabilize and concentrate them before shipping, or to improve the operation of their method.

Technological background and state of the art

[0003] In the energy field, the concept of biomass encompasses all organic matter that may become energy sources. This organic matter, which comes from plants, is a form of storage for the solar energy captured by plants. It may be used either directly (energy wood), or after methanization of the organic matter (biogas), or after new chemical transformations (biofuel).

[0004] Torrefaction refers to a thermal treatment of biomass at no more than 350°C, generally in the near-absence of oxygen and sometimes under inert flushing, which makes it possible to concentrate the energy in the material and make the latter more brittle and therefore easier to crush. Biomass torrefaction is a method quite similar to coffee roasting. However, in the case of wood torrefaction, the issue of the fluidity of the entrainment of the material in the method is much more pronounced, since coffee seeds assume the ideal ball shape.

[0005] Industrial-type torrefying installations are currently known which, in a first phase, comprise thermal pretreatment in the form of in-depth drying done to adjust the moisture of the biomass. This pretreatment releases water, including bound water,

which is at the source of shrinkage of the wood. The dried wood includes from 10 to 15% surface moisture and about 20% at the core. In a second phase, the biomass is made fragile by gentle thermal treatment, which is the torrefaction strictly speaking, without air, and which will be followed by crushing, making it possible to adjust the particle size to the desired value. In this step, the lignins, celluloses and hemicelluloses of the wood are “degraded”. The lignin polymer networks are rearranged; this phenomenon, appearing from 160°C, gives the wood a hydrophobic nature. The torrefied wood thus has its hygroscopic equilibrium around 3%.

[0006] Methods are thus known for torrefying biomass to make it an improved fuel, using technologies of the rotary furnace, stage furnace, liquid- or steam-saturated tunnel furnace, screw furnace or fluidized bed type.

[0007] The current multiple hearth furnaces are a mature technology. These vertically-arranged furnaces operate under atmospheric pressure, in a temperature range from 250 to 1050°C and with a reaction surface having a capacity for example reaching up to 550 m². They also have the advantage of mixing the product continuously. They are used in the environmental field (pyrolysis of solid waste, coal regeneration and biomass transformation) and in the field of raw materials (calcination and recrystallization of industrial ores as well as pyrometallurgy).

[0008] Figure 1 schematically shows a multiple hearth furnace 1, also called MHF below, according to the state of the art. The latter may for example assume the form of a series of circular hearths or heating plates 2, arranged in parallel above one another in a steel casing 3 carpeted with refractory material. A vertical rotating shaft 4 arranged along the axis of the furnace bears arms provided with rabbles 5, i.e., rake-forming tools, which mix the load supplying the furnace at its upper end 6 and which move it through each hearth 2 along a spiral path. The material moves in two adjacent hearths in opposite directions (respectively toward the center and toward the outside of the furnace, and vice versa). To that end, the successive hearths 2 are provided with orifices respectively located near the vertical shaft and the diametrical end of the hearths. The biomass or the load in general is provided at the upper hearth and rabbled to pass through the latter through the aforementioned orifices emerging on the immediately lower hearth, and so forth. It therefore passes in this manner over and

through each hearth 2 toward the bottom of the installation 7 where the product is unloaded. Hot gases 13, for example flue gases, generally circulating countercurrent from the load, bring the furnace to the desired temperature and cause the desired thermal treatment reaction(s) (in-depth drying, torrefaction, etc.) of the load. The heat is therefore produced by the combustion either of the components of the load itself, or of the auxiliary fuel. For example, liquid fuel burners 8 can be provided through the outer casing at some of the hearths. It is also possible to inject steam into the furnace to improve the control thereof. The installation generally operates under a controlled atmosphere and comprises means for controlling the temperature and residence time of the load in the furnace. The load supply can be adapted continuously so as to keep the thickness of the bed mixed inside the furnace constant.

[0009] This type of furnace, which may reach temperatures of around 1000°C, generally comprises large quantities of refractory material pressed on the outer casing. The latter are generally made up of bricks assembled in self-supporting structures said to be in the form of a “Chinese hat”, well known to one skilled in the art. The thickness of refractory material typically ranges from 10 to 30 cm. Furthermore, the central shaft of the furnace must be cooled by a device 9 known to one skilled in the art.

[0010] Document WO/2012007574 A1 discloses a multiple hearth furnace that provides for re-injecting the incinerated pyrolysis gases directly on the product, and claims to physically separate (through product advance mechanisms, the generated gases) the drying zone from the torrefying zone.

[0011] Document US/20130098751 A1 discloses a vertical furnace, half of which is made up of a plate furnace and the other half of which is made up of a vertical shaft kiln, and which operates under pressure (minimum 3 bars). The product is directly exposed to a hot gas.

[0012] Document US 8,276,289 B2 discloses a rotating plate furnace (with a fixed scraper arm). The product is heated directly by the injection of hot gases into the reactor.

[0013] Document US 2013/0228443 A1 discloses a rotating plate furnace on which the product is dried, then torrefied owing to direct contact with incinerated pyrolysis gases.

[0014] Document US 4,702,694 A describes a MHF furnace with hollow hearths that heat the product by indirect pyrolysis, but the hearths are heated inwardly in a traditional manner by the flue gases of a fuel.

[0015] Document CN104048516 A describes a vertical worm kiln.

[0016] The use of the multiple hearth furnace with a typical design in the prior art (with its burners, refractory material, cast parts, etc.) has too much thermal inertia due to the quantity of refractory material present, is too expensive and consumes fossil fuels, which makes it poorly dimensioned and unsuitable for environmental concerns, particularly for use in low-temperature thermal treatment (<350°C).

[0017] Document FR 2 574 810 A1 discloses a multiple hearth reactor and a thermal treatment method for carbonaceous organic material under controlled pressure and temperature conditions. The reactor comprises a pressurized container in particular containing a series of superimposed lower annular hearths defining a reaction zone. The reactor comprises, at its apex, an intake orifice for the introduction of the pressurized material that is transferred by scraping arms while being directed alternately toward the inside and toward the outside, and which cascades downward to cross through the preheating zone and the reaction zone. The improved reaction product is extracted from the bottom, while the residual water and the produced gas are extracted from the apex of the preheating zone. The hot reaction gases produced in the reaction zone pass countercurrent so as to preheat the material in the preheating zone and release and extract its moisture.

[0018] Document US 2016/0017235 A1 discloses a method for treating a waste supply load using a gasifier as well as the gasifier for carrying out the method. A hot exhaust gas coming from a motor travels through a series of hollow heating plates stacked vertically inside a gasification reactor with spaces between each set of successive heating plates forming reaction zones. Each reaction zone is divided into an upper treatment zone and a lower treatment zone by a rotary disc. The waste moves from an outer supply spot along the upper surface of the rotary disc, radially inward in a drop area located on the radially innermost part, from which it falls to the upper surface of the hollow heating plate below. The waste material is next conveyed radially outward in a trough toward the following reaction zone, or once it is completely treated, to an

outlet of the reactor. The vapors from the waste material are aspirated in each reaction zone through an outlet orifice for subsequent treatment.

Aims of the invention

[0019] The present invention aims at transforming waste or biomass at a low temperature, in a multiple hearth furnace designed to best decrease the capital expenditure (Capex) and the operating expenditure (Opex), while preserving the operational assets of the MHF.

Main features of the invention

[0020] The present invention relates to a multiple hearth furnace for thermal treatment at a temperature not exceeding 350°C, comprising an upper inlet for material to be thermally treated, a lower outlet for treated material, a rotating central shaft, a heating device for the material to be thermally treated, an outer casing to which a plurality of hearths are fastened, at least one rabble arm provided with rabble tines above each hearth, rotated by the rotating central shaft, said hearths alternately and respectively having a material unloading opening proximal to the shaft and a material unloading opening distal to the shaft, so as to give the material to be treated a spiral path along the height of the furnace, the hearths being made up of flat discs fastened to the outer casing, the rabble arms being fastened to mechanically welded modules making up the central shaft, the rabble tines being welded to their respective rabble arm, all of these elements being made from sheet metal, i.e., from metal sheets or plates, said multiple hearth furnace being characterized in that the aforementioned heating device comprises a radiant heat exchanger in the form of a flat heat exchange structure comprising thermal fluid ducts, secured to the face of each hearth not being in contact with the material to be treated, and in that the flat heat exchange structure comprising thermal fluid ducts comprises a set of individual ducts made from tubes in a single piece bent in the form of small sections in sector form.

[0021] According to preferred embodiments of the invention, the multiple hearth furnace further comprises at least one of the following features, or an appropriate combination thereof:

- the metal material is stainless steel;
- the fasteners can be disassembled, which is advantageous based on the maintenance;
- the two aforementioned types of hearths, depending on the position of their material unloading opening, comprise metal sheets or plates in the form of sectors, bolted or welded to one another to form a flat disc-forming structure, placed on arms, made from metal and also fastened to the outer casing;
- the rabble arms are assembled at each stage to the rotating central shaft, while being separated from one to the next by a determined and constant angle;
- from one stage to another, the rabble arms are offset by a constant determined angle;
- each rabble arm assumes the form of a beam or a metal profile with straight tines parallel to one another and perpendicular to the arm, but forming, with the axis thereof, an angle different from 90°;
- two consecutive stages of rabble arms are assembled on a modular element of the central shaft of the furnace, said modular element having housings, for example with a rectangular section where the rabble arms are bolted, different central shaft modules being vertically connected, for example fitted, to one another;
- the two types of hearths have heat exchange structures with different respective sector forms because the circular orifice of the hearth for the passage of the load and gases is either central or peripheral;
- the assemblies of sectors are clipped to the back of the hearths on the surface that is not in contact with the load;

[0022] The multiple hearth furnace according to the present invention may for example be used in a drying and torrefying method for wood at a temperature below 350°C, characterized by at least the following steps:

- the wood is cut in a pair of shears that is incorporated or not into the installation,
- the cut wood is dried in a dryer,
- the cut and dried wood is pyrolyzed or torrefied in the aforementioned multiple hearth furnace,
- the material leaving the multiple hearth furnace is reduced into “chips” in a crusher and a press to obtain a pellet,
- the pellet is burned in a solid fuel boiler producing, as output, flue gases and steam powering a turbine/alternator unit,
- energy is recovered by the dryer,
- the flue gases leaving the boiler pass through a heat exchanger that brings a thermal fluid that will heat the multiple hearth furnace to a predetermined temperature,
- a pyrolysis gas generated by the multiple hearth furnace is also injected as fuel into the boiler.

[0023] The multiple hearth furnace according to the invention may also advantageously be used in part to dry the material to be treated or even exclusively to perform drying.

Brief description of the figures

[0024] Figure 1, already mentioned, schematically shows a multiple hearth furnace according to the state of the art.

[0025] Figures 2A and 2B show interior overviews of an example embodiment of the multiple hearth furnace according to the present invention.

[0026] Figure 3 schematically shows an embodiment of a torrefying method using a multiple hearth furnace according to the present invention.

[0027] Figure 4 shows a view of the outer casing of the furnace according to figures 2A and 2B.

[0028] Figures 5A respectively show an outer elevation view and a sectional view of the aforementioned furnace.

[0029] Figures 5B show planar views of two adjacent hearths of the aforementioned furnace.

[0030] Figures 6 show several views of rabble arms, according to an assembly on the rotating shaft of the aforementioned furnace.

[0031] Figures 7 show different views of an individual rabble arm.

[0032] Figure 8 shows one of the modular elements of the rotating shaft of the aforementioned furnace.

[0033] Figures 9 show examples of thermal oil heat exchangers specially adapted to the two types of respective hearths.

Description of preferred embodiments of the invention

[0034] The present invention proposes a multiple hearth furnace, called “MHF 100/0” (standing for 100% metal, 0% injected fuel), particularly suitable for low-temperature thermal treatment, in particular torrefying and/or drying of waste or biomass, essentially by:

- replacing the components of the rabble mechanics by a mechanically welded and non-cooled assembly;
- replacing internal refractory material with standard outer insulating material;
- replacing hearths in the form of a “Chinese hat” with flat metal hearths;
- replacing fossil fuel burners with radiant tubings with thermal oil, fastened below the hearths;
- replacing the fossil fuel with a fatal power source, for example via a simple flue gases/thermal oil exchanger.

[0035] Advantageously, the majority of the metal components for producing such a furnace are standard stainless steel components that are readily commercially available.

[0036] An overview of one example of such a furnace is shown in figures 2A and 2B.

[0037] Figure 3 shows an example torrefying method using a multiple hearth furnace according to the present invention. Wood, for example with a moisture level of 50%, is cut in shears 101, dried in a dryer 102 and next treated, i.e., pyrolyzed or torrefied, with a residual moisture of 10% for example in the MHF 103. At the outlet of the MHF, a crusher and a press 104 reduce the “chips” obtained at the outlet of the MHF into a brown pellet that is burned in a traditional solid fuel boiler 105. The latter produces steam supplying a turbine/alternator unit 106. Condensate water 108 at the outlet of the boiler can be recovered by the dryer 102. The flue gases at the outlet of the boiler 109 pass through a heat exchanger 107 that brings the thermal oil 110 that will supply the MHF furnace 103 to the appropriate temperature. The pyrolysis gas 111 generated by the MHF 103 can also be injected into the boiler 105.

[0038] According to one preferred embodiment of the invention, shown in figures 4, 5A, 5B, 6, 7, 8 and 9, most of the metal components of the furnace, the temperature of which must typically not exceed 400°C, are made from commonly used stainless steel. For example, the outer casing 3 of the furnace can be made from a cylinder in stainless steel sheet “316” (suitable for wet and corrosive environments) for example being 1.5 cm thick. Both types of hearths 2 are also made from plates in stainless steel sheet that may or may not have this thickness, in the form of sectors 21, placed on arms 22, made from stainless steel also fastened to the casing 3 (Figures 5A and 5B). The hearths 2 therefore assume the form of flat discs. In light of the elimination of the mass of refractory bricks, there is indeed no longer any reason to produce self-supported hearths in the form of a “Chinese hat”. Here, a sector refers to a circular sector of a disc, i.e., the surface delimited by two radii and an arc of circle.

[0039] As shown in figure 6, in this particular embodiment, the rabbles 5, of which there are 4 in this non-limiting example, are assembled at each stage, separated from one to the next by an angle of 90°. From one stage to another, the rabbles 5 are offset by 45° (in quincunx). Advantageously, the fasteners of the rabbles and other metal parts are made by bolting, welding, riveting, stapling, crimping or interference fitting. For maintenance purposes, these fasteners will furthermore advantageously be removable.

[0040] As shown in figure 7, the rabbles 5 assume the form of a stainless steel arm, for example a tube with a rectangular section, provided with straight tines 15

parallel to one another and perpendicular to the arm, but forming, with the axis thereof, an angle different from 90°, chosen to obtain the best possible rabbling efficiency.

[0041] Two consecutive stages of rabbles 5 will be assembled on a modular element 14 of the central shaft 4 of the furnace, shown in figure 8. This modular element 14 has housings with a rectangular section 16 where the arms of the rabbles 5 can be bolted. Likewise, the different shaft modules 14 can be connected vertically, for example bolted or fitted, to one another. The maintenance is made easier by the fact that both the broken or defective (bolted) mechanically welded arms and the worn (welded) rabble tines can be disassembled and replaced easily.

[0042] According to another embodiment of the invention, the hearths of the furnace will be heated individually by flat structures of thermal oil ducts 17, 27 associated with the lower surface of each hearth 2. The lower surface of the hearth 2 will be covered by a set of individual ducts preferably made from tubes in a single piece bent in the form of small sections such as sectors 37, 47. Each duct element will have a width decreasing toward the center of the furnace (“sector” form) giving this element the form of a “Christmas tree”. Both types of hearths 2 will have respective exchangers 17, 27 with different sector 37,47 forms due to the fact that the circular orifice of the hearth for the passage of the load and the gases is either central or peripheral. This assembly of the exchanger in small sections 37, 47 is advantageous for the transport, installation and maintenance of the exchangers. This individual exchanger system per hearth also allows a precise adjustment of the temperature, hearth by hearth, for example by acting on the flow rate of the oil circulating in the sectors. Also advantageously, the sector assemblies can be clipped on the back of the hearths (on the surface not in contact with the load) so as to allow easy disassembly of these exchangers.

<u>General advantages of the invention</u>

[0043] The advantages of the invention are as follows:

- total retention of the principle of temperature regulation by hearth, so as to obtain a precise thermal profile;

- total retention of the principle of modular design specific to the MHF: diameter and number of hearths adaptable to the required treatment capacity;
- significant savings due to the drastic decrease in the volume of insulation and refractory material, replacement of large cast steel parts by mechanically welded assemblies and the elimination of the air cooling system and fossil fuel burners;
- greatly reduced thermal inertia;
- resistance to acids and moisture thanks to a careful selection of stainless steel;
- ease of cleaning owing to an internal environment made completely in metal;
- reduced ecological footprint given that the thermal power generation does not require fossil fuel combustion;
- compact, simplified, lightweight design, resulting in reduced construction time;
- pre-assembly before delivery, resulting in further reduced assembly time;
- no combustion system, resulting in reduced maintenance;
- easily programmable maintenance, since the modular aspect of the furnace allows minor repairs without completely stopping the assembly;
- Capex reduction estimated at 40-50%.

List of reference symbols

1 Multi hearth furnace (MHF)
2 Hearth made from refractory material or metal
3 Outer casing
4 Central shaft
5 Rabble arm
6 Upper inlet of the load
7 Lower outlet of the load
8 Fossil fuel burner
9 Cooling of the central shaft
10 Motor of the central shaft

11 Central unloading orifice of the hearth
12 Outer unloading orifice of the hearth
13 Flue gases
14 Mechanically welded module of the central shaft
15 Rabble tines
16 Central shaft flange or sleeve for rabble arms
17 Oil heat exchanger for central unloading hearth
21 Hearth individual sector
22 Hearth support arm
27 Oil heat exchanger for peripheral unloading hearth
37 First exchanger element
47 Second exchanger element
101 Shears
102 Dryer
103 MHF
104 Crusher/press
105 Boiler
106 Turbine/alternator
107 Heat exchanger
108 Condensate water
109 Boiler outlet flue gases
110 Thermal oil
111 Pyrolysis gas

CLAIMS

1. A multiple hearth furnace (1) for thermal treatment at a temperature not exceeding 350°C, comprising an upper inlet (6) for material to be thermally treated, a lower outlet for treated material (7), a rotating central shaft (4), a heating device (8, 17, 27) for the material to be thermally treated, an outer casing (3) to which a plurality of hearths (2) are fastened, at least one rabble arm (5) provided with rabble tines (15) above each hearth (2), rotated by the rotating central shaft (4), said hearths (2) alternately and respectively having a material unloading opening proximal to the shaft (11) and a material unloading opening distal to the shaft (12), so as to give the material to be treated a spiral path along the height of the furnace, the hearths (2) being made up of flat discs fastened to the outer casing (3), the rabble arms (5) being fastened to mechanically welded modules (14) making up the central shaft (4), the rabble tines (15) being welded to their respective rabble arms (5), all of these elements being made from metal sheets or plates, said multiple hearth furnace (1) being characterized in that the aforementioned heating device comprises a radiant heat exchanger in the form of a flat heat exchange structure for the individual heating of each hearth (2) comprising thermal fluid ducts (17, 27), secured to the face of each hearth (2) not being in contact with the material to be treated, and in that the flat heat exchange structure comprising thermal fluid ducts (17, 27) comprises a set of individual ducts made from tubes in a single piece bent in the form of small sections in sector (37, 47) form.

2. The multiple hearth furnace (1) according to claim 1, characterized in that the metal material is stainless steel.

3. The multiple hearth furnace (1) according to claim 1, characterized in that the fasteners can be disassembled.

4. The multiple hearth furnace (1) according to claim 1, characterized in that the two aforementioned types of hearths (2), depending on the position of their material unloading opening, comprise metal plates in the form of sectors (21), bolted or welded to one another to form a flat disc-forming structure, placed on arms (22), made from metal, also fastened to the outer casing (3).

5. The multiple hearth furnace (1) according to claim 1, characterized in that the rabble arms (5) are assembled at each stage to the rotating central shaft (4), while being separated from one to the next by a determined and constant angle.

6. The multiple hearth furnace according to claim 5, characterized in that from one stage to another, the rabble arms (5) are offset by a constant determined angle.

7. The multiple hearth furnace (1) according to claim 1, characterized in that each rabble arm (5) assumes the form of a beam or a metal profile with straight tines (15), parallel to one another and perpendicular to the arm, but forming, with the axis thereof, an angle different from 90°.

8. The multiple hearth furnace (1) according to claim 1, characterized in that two consecutive stages of rabble arms (5) are assembled on a modular element (14) of the central shaft (4) of the furnace, said modular element (14) having housings, for example with a rectangular section (16) where the rabble arms (5) are bolted, different central shaft modules (14) being vertically connected, for example fitted, to one another.

9. The multiple hearth furnace (1) according to claim 1, characterized in that the two types of hearths (2) have heat exchange structures with different respective sector (37, 47) forms because the circular orifice of the hearth (2) for the passage of the load and gases is either central or peripheral.

10. The multiple hearth furnace (1) according to claim 8, characterized in that the assemblies of sectors are clipped to the back of the hearths (2) on the surface that is not in contact with the load.