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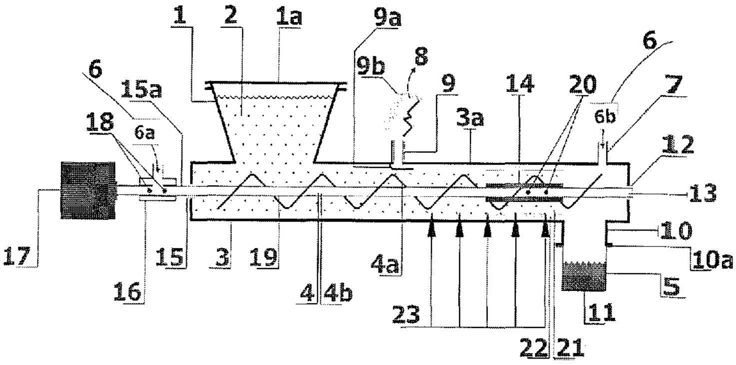

Fig.1

(57) Abstract: The horizontal gasifier features a closed body (3) with thermal insulation containing a helical feed screw (4) for the feedstock (2), a vertical feed inlet (1) for the feedstock (2) located at one end of the body (3), an inlet (7) for the oxidizing gas (6), and an ash collector (5) at the other end of the body (3), and an outlet (9) for volatile products (8). The gasifier is characterized by a gasification zone (21) in the final section of the body (3), with the shaft (4b) of the helical feeder (4) being completely hollow along its length and equipped with inlet openings (18) for introducing a supplementary portion of oxidizing gas (6) located in a segment extending beyond the body (3) on the side where the feed inlet (1) is located, and outlet openings (20) for this portion of oxidizing gas located in the gasification zone (21). The outlet (9) for volatile products (8) is positioned between the feed inlet (1) and the inlet (7) for the oxidizing gas (6). Both the inlets (7) and (18) for the oxidizing gas (6) are equipped with independent mass flow meters (6a) and (6b) connected to at least two temperature sensors (23) placed within the body (3). The invention also encompasses a method for the thermochemical conversion of combustible carbonaceous material (2) in a horizontal gasifier.

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Horizontal Gasifier and the Thermochemical Conversion of Combustible Carbonaceous Material in a Counter-Current Process

The subject of the invention is a horizontal gasifier with a movable bed of comminuted matter used for its counter-current partial pyrolysis and further gasification of any combustible carbonaceous materials.

The pyro-gasification process involves the gradual thermochemical decomposition of combustible carbonaceous materials and their transformation into other volatile substances. The primary products of such decomposition are carbon monoxide (CO), hydrogen (H_2), hydrocarbons, and other organic substances in gaseous or vapor-mist form. The solid product leaving the device is ash, which remains as residue after the mineral/inorganic components of the feedstock; this ash can be completely coke-free or intentionally contain tar-free coke fertilizer.

Minor fouling of the gas with tars from known carbonaceous feedstock gasification devices does not pose a significant problem for the straightforward combustion of such gas but is associated with the risk of resinous deposits in supply pipes, valves, and the burner itself. For modern cogeneration and chemical applications, however, completely tar-free gas is required. Consequently, for over a century, there have been patent descriptions of increasingly complex (and predominantly vertical) co-current (downdraft) gasifiers, both small and large, proposing the production of clean generator gas (also known as process gas). However, no solution offers fully satisfactory cleanliness, so such gas must be purified through filters or scrubbers. This, in turn, poses a new problem of disposing of deposited/precipitated tars (and sometimes soot or very fine coke). Such installations (tar and dust removal and their elimination) are usually larger than the modern gasifiers themselves.

In co-current (downdraft) gasifiers, the tar generation process occurs very close to the gasification zone – so the tars should decompose completely there. However, colder "channels" of gas are created in this zone, causing some tars to settle on the cold coke blown out of this gasification zone. Such unburned coke carries a portion of the chemical energy of the feedstock and, due to contamination with carcinogenic tars, cannot be used as a bio fertilizer. Therefore, it is directed to special (and costly) landfills or cautiously burned in separate installations.

In counter-current (updraft) gasification, combustible carbonaceous material (feedstock) moves in the opposite direction to the introduced primary oxidizer (oxygen O_2 from the air) and then gases/vapors resulting from the interaction of this oxidizer with the feedstock. Such counter-current motion is rarely encountered in practical gasifier solutions because the generated process gas contains too many tars generated in the inevitable stages of torrefaction and initial feedstock pyrolysis.

In the case of vertical counter-current gasifiers, one of the inconveniences is the spontaneous and uncontrolled movement of the feedstock, which is gravity-driven and filled from the top. The free space left after the feedstock has burned, pyrolyzed, or torrified, usually near the mandatory grate, gets occupied by a portion of the feedstock falling from above, causing a cascading collapse of higher layers until it reaches the top of the gasifier, where space is freed up for adding a new batch of feedstock. Not always do these empty spaces fill up on their own (and quickly) due to the complex structure of feedstock components such as splinters, pins, plates, rags, plastic scraps, agglomerations, and more. Vertical "chimneys" are formed through which gas and residual oxygen from the air preferentially find their counter-current path towards the upper outlet of the gasification's volatile product, instead of navigating through the slightly compacted feedstock. Sometimes, vibration, tapping, etc., help in eliminating these "chimneys." However, it is precisely during the gas's passage through the feedstock (rather than escaping through "chimneys") that the most crucial heat and matter exchange processes occur, including drying, torrefaction, pyrolysis, and eventually gasification.

The description of the Polish patent PL 231641 mentions a vertically-horizontal gasifier with a fixed bed. This gasifier has a main vertical body closed by an active carbonizing grate. In the upper part of the vertical body, there is an inlet for the combustible carbonaceous material. Below the active grate in the lower part of this vertical body, there is a short horizontal screw conveyor with a ribbon screw with sections of full coils.

From the description of the Spanish patent ES 2315029, a horizontal pyrolytic gasification reactor is known, consisting of two concentric chambers, a gasification chamber and a cooling chamber. The cylindrical gasification chamber has multiple nozzles for introducing preheated air evenly distributed along its length, e.g., with an inlet every 1.5 meters, allowing for division into zones to control the gasification temperature. Inside this chamber, a conveyor is installed, which can be a screw conveyor for part of its length.

In both of the horizontal gasifiers described above, the gasification process of combustible carbonaceous materials occurs in a co-current manner, meaning the oxidizer introduced moves in the same direction as the material being gasified.

Despite the significantly higher contamination of gas with undesired tars generated in counter-current gasifiers, this very type of device has become the subject of this invention. The goal of this invention is not to reduce but to increase the tarring of the final volatile product coming out of such a gasifier. This product becomes the feedstock in a separate device, which immediately and selectively oxygenates all undesirable substances in the gas leaving this gasifier, including condensed mists of tars and carbon dust. All these "dirty" and problematic components of the hot process/generator gas serve as the feedstock for this next device to produce an additional amount of very clean and tar-free synthesis gas, mainly consisting of hydrogen (H_2) and carbon monoxide (CO).

The current invention also solves the problem of randomly appearing and changing "chimneys" by applying forced horizontal movement of the feedstock through its controlled rotary-linear motion throughout the gasifier's body.

Furthermore, this invention aims to simplify the device's construction, reduce its dimensions, facilitate access to mechanisms (servicing), simplify flow rate adjustment, enable containerization of devices, and expand the list of potential feedstocks (including tarry ones).

The gasifier according to the invention features a horizontal, closed, thermally insulated body in which a screw feeder with controlled drive is placed.

At one end of the body, there is a vertical feed inlet for the material to be gasified, and at the other end, there is an ash collector and an inlet for the oxidizing gas passing counter-currently toward the feed inlet. Between the ash collector and just before the feed inlet, there is an outlet for the volatile pyro-gasification products. In the final zone of the body, there is the gasification zone, where the first contact of the oxidizing gas with the feedstock occurs, and the highest temperatures are observed, even exceeding 1200 °C. In the gasification zone, the body is additionally equipped with an inner layer of thermal insulation. The screw feeder has a shaft that is tightly hollowed along its entire length and equipped with an inlet hole for the oxidizing gas on the part extending beyond the body on the side where the vertical feed is located. It also has small outlet holes for the oxidizing gas in the gasification zone. A portion of the screw shaft with the inlet hole for the oxidizing gas is placed in a sealed canister/distributor. Two separate inlets for the oxidizing gas are equipped with their mass flow meters connected to at least two temperature sensors placed in the gasifier's body.

The advantageous features of the screw feeder are thermally insulated in the same zone where the gasifier's body is equipped with an inner layer of high-temperature thermal insulation.

The advantageous outlet for volatile products is equipped with a shield to prevent it from becoming clogged by the feedstock.

The advantageous feed inlet is equipped with a tight flap to prevent the leakage of volatile products into the surroundings.

The advantageous body can have any closed cross-section, such as a circle, ellipse, triangle, square, rectangle, polygon. The advantageous body is made of metal with a melting temperature higher than 1200 °C, for example, steel.

Advantageously, in the gasifier according to the invention, the outer diameter of the screw feeder's flights is at least 2 cm smaller than the smallest linear gap in the body throughout its length.

The essence of the invention is also a method of thermochemical conversion of combustible carbonaceous material in a counter-current process in a horizontal gasifier, wherein the carbonaceous material introduced into the gasifier's body through a vertical feed is moved using a horizontal screw feeder towards the end of the body, where the gasification zone of gasification is located. Simultaneously, an oxidizing gas is introduced in a counter-current system, and the resulting volatile products of the interaction of the gas with the feedstock are discharged through an outlet located in the upper cover of the gasifier near the feed inlet. The solid product is collected at the end of the body opposite to the feed inlet, with a portion of the oxidizing gas supplied from the side of the feed inlet through a sealed conduit with an inlet hole at one end and outlet holes at the end located in the gasification zone.

Advantageously, for a given screw feeder rotation speed regulating the mass flow rate of a given feedstock, expressed in kg/h, the total flow rate of the oxidizing gas, expressed in kg/h of free oxygen (O_2), is controlled by feedback from the calorific value analyzer or the heat of combustion of all gaseous and vapor components of the gasification products of carbonaceous material exiting through the outlet. This is done with at least two mass flow rate regulators for the oxidizing gas to achieve the maximum Heat of Combustion of these products, expressed in potential enthalpy kilowatts.

Advantageously, the portion of the oxidizing gas supplied from the side of the feed inlet constitutes 20 to 30%.

Advantageously, the sealed conduit for supplying a portion of the oxidizing gas constitutes a hollowed screw feeder shaft. This portion of the oxidizing gas is dosed with a mass flow rate meter located at the inlet to the hollowed screw feeder shaft. The dosing of the oxidizing gas is controlled automatically based on readings from temperature sensors immersed in at least two of the hottest places in the gasifier's body.

The oxidizing gas can be atmospheric air or air enriched with oxygen (O_2) up to a maximum of 90% by volume. The oxidizing gas can be at ambient temperature or heated with waste heat. Such enriched air can be obtained from readily available oxygen concentrators, e.g., for oxygen therapy or diving.

Advantageously, the space between the screw flights and the inner walls of the body is filled with the feedstock or solid products of the gradual conversion of this feedstock along the entire length of the screw from the feed inlet to the beginning of the ash collector.

Advantageously, the combustible carbonaceous material subjected to pyro-gasification is a solid, dry or slightly moist material with a particle size not exceeding the narrowest gap between the screw flights and the closest inner walls of the body. It can also be a mixture of such a material and oily substances in proportions that allow the free flow of the oxidizing or process gas through the feedstock pushed by the screw, filling the entire gasifier body up to the sealed ash collector.

The gasifier according to the invention operates in such a way that the combustible carbonaceous material is fed into the body through a vertical feed. The feedstock is moved horizontally within the body using a screw feeder towards the end of the body, where an ash collector is located. Such a screw is loosely placed along the axis of the gasifier body with slightly more space around the screw, which in turn leaves a section sufficiently filled with the feedstock but always permeable to the forced flow of gases and vapours through it. The loose arrangement of the screw flights, with a diameter slightly smaller than the closed body in which they are placed, prevents the screw from jamming with accidental feedstock chunks.

Most of the oxidizing agent is supplied through the inlet into the body from the side of the sealed ash collector. This oxidizing agent, while passing through the feedstock, causes partial oxidation due to the thermochemical interaction with the feedstock, resulting in the formation of pyro-gasification products. These products then continuously and counter-currently move along the moving feedstock towards the outlet located in the body between the feed inlet and the ash collector. All gases, vapours, mists, and dust exit through this outlet as the products of pyrolysis and gasification of the carbonaceous material. The remaining solid product is collected at the end of the body opposite to the feed inlet and near the sealed ash collector. The solid product is either free of coke (or intentionally coke-poor) and is collected in the sealed ash collector.

The initial driving factor of the gasification process is, therefore, the oxidizing agent in the form of molecular oxygen (O_2) present in atmospheric air or air enriched with oxygen up to 90% by volume. Continuous contact of oxygen with the combustible carbonaceous material initially leads to the localized and complete combustion of a small portion of this material, releasing heat, CO_2

(carbon dioxide), and water vapor (H_2O_v) as the main products of this combustion. In this part of the gasifier, temperatures reach 1200 °C or even higher. The products of this combustion, mainly CO_2, H_2O_v, and the inert nitrogen from the air, completely depleted of oxygen at this point, heated to such high temperatures are highly chemically reactive. These gaseous/vapor intermediate products are directed towards the gasifier's outlet, passing through successive sections of the moving carbonaceous material and causing various thermal and chemical processes within it. The primary and very hot CO_2 and H_2O_v undergo reduction reactions during this counter-current journey, converting them into carbon monoxide (CO) and hydrogen (H_2) by releasing their oxygen atoms (O) to the encountered carbonaceous material. Thus, CO_2 and H_2O_v become secondary oxidizing agents.

From the perspective of the solid material (feedstock) continuously introduced at ambient temperature (or slightly higher) into the gasifier's inlet, the material is gradually heated and undergoes physical (drying) and chemical transformations due to the hot gases and vapours passing through it. At the outlet of the device, only coke-free (or intentionally coke-poor) mineral ash remains from this material. The solid organic carbonaceous material in a solid state, containing bound hydrogen, oxygen, nitrogen, and certain other elements like S, Cl, P, undergoes transformation and transfer into the counter-currently flowing gases and vapours. It is also possible an incomplete (and intentional) gasification in case of an oxygen supply deficit, and in such cases, the ash will contain elemental carbon in the form of coke.

The history of the combustible carbonaceous feedstock (or charge) can also be briefly described as follows: initially cold (or warm) and slightly moist => dry and more heated => hot and torrefied => partially pyrolyzed ("pyrolysate") => glowing coke => cold coke-free ash or ash with a deliberate addition of tar-free coke (for the production of "bio-coal," "char", "biochar," "agrochar" or the like).

The history of the carbonaceous feedstock can be shorter if the feedstock has previously been torrefied: cold (or warm) => dry and hot => pyrolysate => glowing coke => cold coke-free ash or ash with a deliberate addition of tar-free coke.

From the perspective of air as an oxidizer, enriched with O_2 (up to 90% by volume) or unenriched, continuously introduced into the apparatus near the ash outlet, the oxidizer is initially preheated by the waste heat of the process or at ambient temperature. The sequence of events is as follows: it first encounters the glowing coke (with some ash content) and rapidly loses all its oxygen to burn the coke entirely or only a part of it. As a result of this process, very hot CO_2 and water vapor are produced in the equally hot nitrogen (N_2) that remains, and this mixture is pushed into further portions of coke in the direction opposite to the feedstock movement. Some of the CO_2 reacts with the coke to form carbon monoxide (CO). In the further portions of the feedstock flowing counter-currently (previously processed by heat and gas components), now deprived of oxygen but still very hot, a mixture of $N_2 + CO_2 + CO + H_2O_v$, it encounters the hot torrefied or pyrolyzed material. This material further thermally decomposes (pyrolyzes) into coke, hydrogen H_2, and a mixture of light and heavy hydrocarbons, as well as more complex volatile organic compounds mainly containing C, H, and O.

The history of the incoming oxidizer (initially containing only $N_2 + O_2$ + the ever-present Argon Ar from the air + possibly moisture) can also be briefly described as follows: heating and complete loss of O_2 with the appearance of CO_2 in the remaining nitrogen (+ Ar) => conversion of some CO_2 into CO => appearance of water vapor, hydrogen, methane (CH_4), and other light hydrocarbons (C_nH_m) => a rapid increase in the concentration of water vapor and tars due to the torrefaction of the feedstock (provided it has not already been subjected to this process) => further increase in the concentration of water vapor due to drying the feedstock => emission of hot gases, vapours, mists, and dust from the pyro-gasification device.

The processes in both counter-current streams can be described by the following chemical reactions (in order of decreasing temperatures of the feedstock, i.e., from the contact of the oxidizer with the glowing coke to the outlet of the vapor/gas product, including $N_2 + H_2 + CO + H_2O_v + CO_2 + C_xH_yO_z$ + tars):

Exothermic: $C + O_2 \Rightarrow CO_2$ $\Delta H°298$ = -393.5 kJ per mole of C (1)

Exothermic: $C + 0.5\ O_2 \Rightarrow CO$ $\Delta H°298 = -110.5$ kJ per mole of C (2)

Endothermic: $C + CO_2 \Rightarrow 2\ CO$ $\Delta H°298 = +172.5$ kJ per mole of C (3)

Endothermic: $C_xH_yO_z \Rightarrow$ C (coke) + CO + H_2 + saturated & unsaturated hydrocarbons (pyrolysis) (4)

Exothermic: $C_XH_YO_Z \Rightarrow C_xH_yO_z$ (torrefied/pyrolyzed product) + H_2O_v (chemical moisture) + tars;
indices X > x, Y > y, Z > z (5)

Endothermic: $C_XH_YO_Z$ (moist biomass) => $C_XH_YO_Z$ (dry biomass) + H_2O_v (physical moisture) (6)

With this organized feedstock movement (regarding the filling of the gasifier) and the forced movement of the feedstock toward the hottest zone of the gasifier, there is no longer a dependence on gravity, allowing the device to be set up horizontally. This facilitates servicing and enables it to be placed in a container (instead of erecting a less accessible tower), which, in turn, allows for desired miniaturization and mobility of the entire installation in line with current trends in distributed energy distribution. However, the key differentiator of the invention is the unique organization of the entire counter-current pyro-gasification process in such a screw conveyor to increase tar generation and avoid grates.

The gasifier according to the invention is shown in more detail in Figure 1 in a schematic view. For example, it has a body 3 made of sheet steel profile in a "U" shape (trough) with a depth of 20 cm and a width of 18 cm. The length of this profile is 2 m. The closed profile is covered with a high-temperature-resistant cover 3a, which can be removed for the inspection of the screw conveyor 4 and other servicing purposes. Inside this closed body 3, there is a screw conveyor 4 with an outer diameter of 14 cm (adapted to this profile). Steel blades 4a of this conveyor are mounted on a long steel pipe 4b with an outer diameter of 40 mm. The interior 19 of this pipe, which serves as the shaft 4b of the screw, allows it to be used for transporting part of the oxidizer 6, i.e., atmospheric air or oxygen-enriched air, to the pyro-gasification process. The steel blades/coils 4a of this screw conveyor, transporting the combustible carbonaceous feedstock 2 to pyro-gasification, have a pitch of 14 cm. This pitch can be changed in the hottest area of the device – the gasification zone 21, where there is intensive conversion of the feedstock 2 into gas and vapor, coupled with a significant reduction in the volume of this feedstock.

The conveyor 4 is centred in the body 3 using two sealed elements: a bearing 15 on the filling side 1 and a loose support 12 that allows the shaft 13 of the screw to deviate up to 1 cm from the geometric axis of the conveyor. This clearance facilitates the movement of feedstock lumps between the filling area and the target gasification zone 21 and allows for overcoming local jams.

The combustible carbonaceous feed 2 is fed evenly or periodically into a hopper 1 with a capacity of about 30 litres, located vertically just above the beginning of the profile and attached to the cover 3a. The conical shape of the hopper and its wide throat facilitate the flow of feedstock onto the rotating screw conveyor underneath. This applies to the example presented here, if the feedstock lumps do not exceed 2 cm in their widest dimension, such as chips, briquettes, granules, or other forms of feedstock fragmentation for pyro-gasification. Excessive fragmentation of the feedstock hinders the process, which requires sufficient permeability of the solid matter traveling counter-currently to gases and vapours. The ideal shape and size of the feedstock are 1 to 2 centimetre spheres, while homogeneous powdered material is not allowed.

The feedstock 2 should contain solid carbonaceous matter, as dry as possible, with a minimal heat of combustion of dry mass (Higher Heating Value HHV) of 6 MJ/kg, such as waste coal, waste wood, or other waste biomass, combustible residues from municipal waste (RDF), or industrial, urban, or agricultural waste. Such material may be oiled or even specially soaked in combustible waste liquids. It should not significantly swell due to heat and, especially, under the influence of water vapor released in the hot pyro-gasification zone and contained in the gaseous products passing through the feedstock moving counter-currently to the gas in the body 3. An example of undesirable feedstock could be a pure, homogeneous pellet made from compressed sawdust, which falls apart and swells.

An important element of the pyro-gasifier is the precisely controlled drive 17 of the conveyor 4. This is a mechanical transmission connected to an electric motor (or another) and with adjustable speed using a controller, e.g., an inverter. The speed of rotation of the screw conveyor 4 is set by the desired hourly feedstock processing rate. The oxidizer flow rate is the result of a logical feedback of the observed temperature distribution in several selected locations along the path of the feedstock 2 to the gasification zone 21. Temperatures are measured by appropriate sensors 23 placed in the traveling feedstock 2. This allows for dynamically stabilizing the optimal temperature distribution along the entire profile 3, from the feedstock filling location to the gasification zone 21, determining the best results for the entire pyro-gasification process.

The gasification zone 21 is the place where the highest temperatures are achieved, exceeding even 1200 °C. Here, full, or partial combustion of the coke from the carbonaceous feedstock 2 occurs according to reactions (1) and (2). This place is additionally insulated from the inside with ceramics 22 on the profile 3. Also, thermally insulated at this point is the shaft 4b of the screw conveyor, using heat-resistant ceramics 14. It is essential to maintain the shaft at the lowest possible temperature to maintain its stiffness against bending and torsion. This is achieved by feeding a portion of the oxidizer 6 needed for pyro-gasification through the interior 19 of this shaft; thus, the supplied portion of the oxidizer, controlled by a flow meter 6a, cools the conveyor shaft, and the heated oxidizer, after exiting through openings 20, releases this captured heat into the nearby gasification zone 21.

The gasification of the remaining coke from the carbonaceous feedstock 2 pushed by the conveyor 4 into the gasification zone 21 occurs thanks to the air (atmospheric or oxygen-enriched) introduced here. Such oxidizing gas 6 is supplied to the gasifier in two places. One portion of the oxidizer is delivered and controlled by a flow meter 6b to the gasification zone 21 directly via a connector 7 located at the end of the profile on the gasification zone side 21. The second portion of the oxidizer is supplied to the gasification zone of the gasifier from the filling side 1, through a flow meter 6a, using a sealed canister 16 on the drive side 17, through input holes 18 into the interior 19 of the screw conveyor shaft 4b, and finally through outlet holes 20 located at the end of this shaft.

The dosing of the oxidizer is, therefore, carried out through two separate mass flow meters on inlets 6a and 6b; it is automatically controlled based on temperature readings from sensors 23 placed in several locations within the traveling feedstock.

For a given feed rate of the combustible carbonaceous feedstock (determining the overall enthalpic power of the gasifier), it is this optimal temperature distribution along this profile, determined by tests, that decides on the best results of the entire pyro-gasification process.

The very hot gaseous and vapor products 8 of coke gasification in the gasification zone 21 have only one way out of the sealed gasifier: counter-currently to the advancing feedstock and at the end via a connector 9 on the cover 3a of the body 3. The location of this connector 9 is chosen so that the gaseous and vapor products 8 of pyro-gasification, resulting from subsequent thermochemical processes, have an optimal chemical composition and a temperature not exceeding 300 °C – this is to prevent the carbonization of tars in the pipe 9b leading them to the next process of their selective oxidation to syngas in a separate reactor. The initial temperature of the products 8 should also be higher than 120 °C to prevent liquid condensation at this point. The connector 9 is equipped with a shield 9a in its lower part to prevent feedstock 2 from entering this connector.

The hot products 8 of pyro-gasification are directed to a separate reactor, in which all tars, heavy and light, as well as all volatile hydrocarbons and other organic compounds, even those containing nitrogen, sulphur, halogens (X), silicon (Si), and other minor elements, undergo decomposition into hydrogen H_2, carbon monoxide CO, nitrogen N_2 or ammonia (NH_3), hydrogen sulphide (H_2S), hydrogen chloride (HX), silicon monoxide (SiO), and other simple and volatile compounds or stable elements in a strongly reducing and hot atmosphere of H_2 and CO.

Another outlet for the products of pyro-gasification from the device could be their further penetration along the screw conveyor to the filling side 1. However, this alternative path is hindered by fresh feedstock 2 that fills the space between the connector 9 and the base of the filling hopper 1 tightly enough, so it is easier for the products 8 to leave the device through the connector 9. A sealed flap 1a covering the filling hopper 1 and opened periodically only for adding feedstock 2 or another sealed device feeding feedstock 2 into the filling hopper 1, e.g., two mechanized guillotine sluices, could also close this path.

Coke-free (or intentionally coke-containing) ash 11 resulting from complete (or partial) combustion of coke in the gasification zone 21 falls, pushed by continuous pressure from the feedstock, into a sealed ash collector 5 located under the wide connector 10 with a coupling 10a. This ash is partially cooled (or burned) by the oxidizing gas 6 flowing to the gasification zone 21 through holes 20 or naturally cooled due to the uninsulated walls of this ash collector (in the case of producing a mixture of ash and agro-coal).

The entire structure of the body from the feed location 1 to the ash collection location 5 is thermally insulated from the external environment with mineral wool or similar insulating materials – which improves the energy efficiency of the feedstock-to-vapor product conversion process.

The source of heat for the entire process of pyro-gasification of the combustible feedstock 2 is the complete (or partial) combustion of part of the same feedstock 2 in the gasification zone 21, where this feedstock, or rather its coke residue after prior pyrolysis (reaction 4), encounters the oxidizing gas 6. This strongly exothermic oxidation (reactions 1 and 2) is initiated by igniting such coke (or feedstock 2 in a cold start of the gasifier) with any source of heat added to the vicinity of the gasification zone 21.

Example 1.

The pyro-gasification process itself is illustrated (and balanced) using a mixture of hardwood, softwood, hardwood bark, and softwood bark in equal proportions. This feedstock 2 can be described with the following elemental composition (by weight % of dry matter): C 51.9; H 6.13; O 41.2; N 0.25; ash 0.50. This dry carbonaceous matter represents a calculated calorific value (HHV) = 21 MJ/kg. However, feedstock 2 had a relative humidity of 19%, which translates to its reduced calorific value = 17 MJ/kg. The hourly feed rate of this feedstock under the conditions of stationary operation of the pyro-gasifier presented in the example was 0.14 tons per hour, which corresponds to an input thermal/enthalpy power of 0.65 MW (the "upper" HHV value considering the condensation of water vapor from combustion).

During stable operation, 0.15 tons of atmospheric air per hour are supplied (equivalent to a flow rate of approximately 115 m^3(n)/h), resulting in a dirty and very humid process gas containing 48 g of tars per 1 m^3(n), i.e., a total of 12 kg/h of tars. After condensing water vapor and tars from a small sample of the product 8, the obtained gas could be analysed chromatographically (dual-channel μGC Agilent Model 490); it exhibits the following composition (by volume %, dry gas): N_2+Ar 48, CO 37, H_2 8, CO_2 2, CH_4 2, C_2-C_4 4.

The flow rate of dry gas devoid of tars (calculated from a mass balance) would be nearly 190 m^3(n)/h. To obtain this gas, however, it would be necessary to condense the water vapor, resulting in 53 kg/h of water, in which most tars would also condense. Such a slurry would be problematic and costly to remove and destroy.

The process gas 8 leaving the nozzle 9 is not cooled but rather thermally insulated from the environment to maintain its initial temperature (up to 300 °C) and composition. The water vapor and tars contained in it are transported by the tube 9b to a nearby special reactor for the subsequent selective conversion of tars and other carbonaceous gases into an additional portion of clean synthesis gas.

The process of partially oxidizing feedstock 2 into the dirty process gas 8 is entirely exothermic because reactions (1) and (2), with heat release, power the remaining processes successively taking place in feedstock 2 moving counter-currently to the supplied air and then to the hot combustion products according to reactions (1) and (2). From the initial heat power of feedstock 2 amounting to 0.65 MW, a standard enthalpic power of 0.56 MW remains in gaseous and vapor products 8, which means that the difference of approximately 0.09 MW "emerged" in the pyro-gasifier. Part of this power was lost to the environment due to imperfect thermal insulation of the body 3, but most of this "thermal" 0.09 MW left the device as heated product 8. To avoid the pyrolysis of tars in the tube 9b connecting the nozzle 9 with the next syngas treatment/conversion device, part of the heat can be directed, for example, to the tank 3 for preliminary drying of feedstock, limiting the temperature of the product 8 to 300 °C. Another way to lower the temperature of the product 8 below 300 °C is to move the nozzle 9 on the plate 3a towards the cold feed 1 - but always maintaining the temperature of the product 8 above 120 °C to prevent the condensation of water vapor and tars in the tube 9b.

As a result of the complete or partial combustion of feedstock 2 residues, i.e., carbon or coke after the processes (1) and (2), in the gasification zone 21, approximately 0.6 kg/h of ash 11 devoid of carbon accumulates in the sealed ash receiver 5. In the case of wood pyro-gasification, this ash will consist only of silicon, calcium, and magnesium oxides, which, after partial neutralization, can be used as a mineral fertilizer. For other highly ashy carbonaceous feedstocks, such final ash 11 can be partially returned and added to the processed feedstock to bind, if present, fluorine, chlorine, and bromine, to the appropriate calcium and magnesium chlorine salts, which will be found in the final ash. Due to the possible toxicity of such ash (if it contains heavy metals), its use to produce concrete or aggregate remains an option.

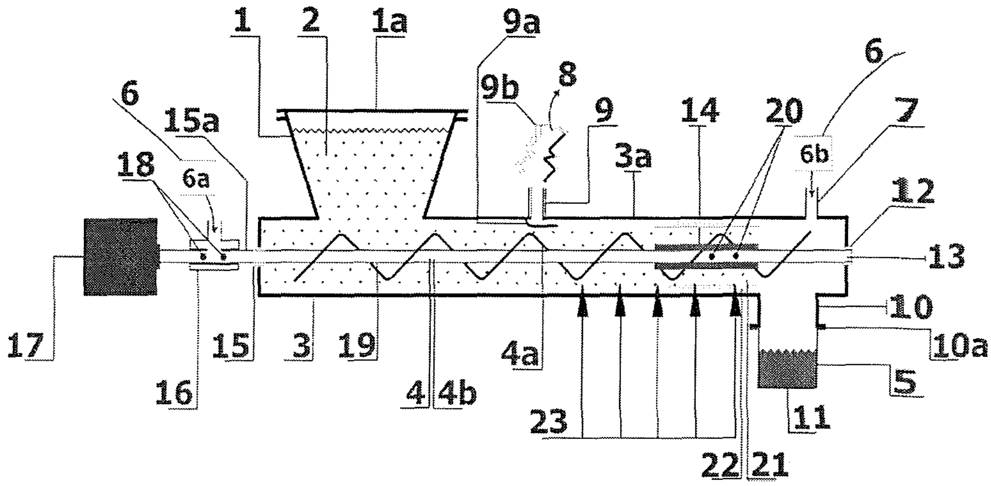
Claims

1. A horizontal gasifier with a closed body (3) equipped with thermal insulation, wherein a helical feed screw (4) for feedstock (2) is located, equipped with a vertical feed inlet (1) for feedstock (2) positioned at one end of the body (3), an inlet (7) for oxidizing gas (6), and an ash collector (5) located at the other end of the body (3), an outlet (9) for volatile products (8), and at least two flow meters and at least two temperature sensors, characterized in that the final zone of the body (3) forms a gasification zone (21), and the shaft (4b) of the helical feeder (4) is completely hollow along its length and equipped with inlet openings (18) for introducing a supplementary portion of oxidizing gas (6) located in a segment extending beyond the body (3) on the side where the feed inlet (1) is located and outlet openings (20) for this portion of oxidizing gas located in the gasification zone (21), and the outlet (9) for volatile products (8) is located between the feed inlet (1) and the oxidizing gas inlet (7), and the inlets (7) and (18) for oxidizing gas (6) are equipped with independent mass flow meters (6a) and (6b) connected to at least two temperature sensors (23) located in the body (3).
2. The gasifier according to claim 1, characterized in that the body (3) in the gasification zone (21) is equipped with an internal layer of thermal insulation (22).
3. The gasifier according to claim 1, characterized in that the segment of the hollow shaft (4b) of the feeder (4) with inlet openings (18) is in a sealed distribution box (16), to which a supplementary portion of oxidizing gas (6) is supplied through a flow meter (6a).
4. The gasifier according to claim 1, characterized in that the hollow shaft (4b) of the helical feeder (4) has thermal insulation (14) in the gasification zone (21).
5. The gasifier according to claim 1, characterized in that the outer diameter of the feeder's helices (4a) is at least 2 cm smaller than the smallest linear gap in the body (3) along its entire length.

6. The gasifier according to claim 1, characterized in that the outlet (8) for volatile products is equipped with a shield (9a).
7. The gasifier according to claim 1, characterized in that the feed inlet (1) is equipped with a sealed flap or gate (1a).
8. The gasifier according to claim 1, characterized in that the body (3) has any closed cross-section.
9. The gasifier according to claim 1, characterized in that the body (3) is made of metal with a melting temperature higher than 1200 °C.
10. A method for the thermochemical conversion of carbonaceous combustible material (2) in a horizontal gasifier, in a counter-current process, comprising feeding the carbonaceous material (2) into the body (3) of the gasifier through a vertical feed inlet (1) and moving it using a horizontal helical feeder (4) towards the end of the body (3), where a gasification zone (21) is located, while simultaneously supplying oxidizing gas (6) in a counter-current arrangement, and collecting solid product (11) at the end of the body opposite the feed inlet (1) for the feedstock (2), characterized in that a part of the oxidizing gas (6) is supplied through an inlet opening (7) located at the end of the body (3) near the gasification zone (21), and a supplementary portion of the oxidizing gas (6) is supplied from the side of the body (3) through a flow meter (6a) located at the vertical feed inlet (1) via a sealed conduit (4b) with at least one inlet opening (18) at one end of the conduit (4b) and outlet openings (20) at the end located in the gasification zone (21), and the resulting volatile products (8) are discharged through an outlet nozzle (9) located in the upper cover (3a) of the central part of the body (3).
11. The method according to claim 10, characterized in that for a given feed rate of a specific feedstock, expressed in kg/h, the total consumption of oxidizing gas (6) expressed in kg/h of free oxygen (O2) is regulated through feedback based on the calorific or heat values of all gaseous and vapor components as products (8) of the pyro-gasification of the carbonaceous material (2) exiting through the outlet nozzle (9), with the mass flow rate of the oxidizing gas (6) controlled automatically by flow

meters (6a) and (6b) based on readings from temperature sensors (23) submerged in at least two locations in the body (3).

12. The method according to claim 10, characterized in that atmospheric air or air enriched with oxygen (O2) up to a maximum of 90% by volume is used as the oxidizing gas (6).
13. The method according to claim 10, characterized in that the supplementary portion of the oxidizing gas (6) supplied from the feed inlet (1) side constitutes from 20% to 30%.
14. The method according to claim 10, characterized in that the oxidizing gas (6) is dosed through two separate mass flow meters: one (6b) at the inlet (7) in the gasification zone (21) and the other (6a) at the inlet to the distributor (16) supplying the oxidizer to the inlet openings (18) on the hollow shaft of the feeder (4).
15. The method according to claim 10, characterized in that the oxidizing gas (6) supplied through the inlet (7) is preheated by waste or process heat.
16. The method according to claim 10, characterized in that the space between the feeder elements (4) and the inner walls of the body (3) is filled with feedstock (2) or solid products of the gradual conversion of this feedstock along the entire length of the feeder from the location of the feed inlet (1) to the beginning of the product collector (5).
17. The method according to claim 10, characterized in that the carbonaceous combustible material (2) subjected to pyro-gasification is a solid, dry, or moist body with a particle size not exceeding the smallest linear gap between the helix (4a) of the feeder and the nearest inner walls of the body (3) or a mixture of such a body with oily substances in proportions still allowing the free flow of oxidizing gas (6) through such feedstock pushed by the helix in a gas-tight body filled with feedstock to a sealed product collector (5).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1a
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Fig.1

INTERNATIONAL SEARCH REPORT

International application No
PCT/PL2023/000049

A. CLASSIFICATION OF SUBJECT MATTER
INV. C10J3/00 C10J3/72
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)
C10J

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 3 358 253 A1 (HERZ ENERGIETECHNIK GMBH [AT]) 8 August 2018 (2018-08-08) figure 1 claims 1-9	1-17
A	US 3 942 455 A (WALLIS KEITH H J) 9 March 1976 (1976-03-09) figures 1-7 claims 1-12	1-17
A	US 2019/118157 A1 (CHANDRAN RAVI [US] ET AL) 25 April 2019 (2019-04-25) figures 5,6	1-17

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"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
15 January 2024	25/01/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lachmann, Richard

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/PL2023/000049

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