(54) Title: A METHOD AND A SYSTEM FOR DECOMPOSITION OF MOIST FUEL OR OTHER CARBONACEOUS MATERIALS

(57) Abstract: A staged gasification process and system for thermal gasification of special waste fractions and biomass, e.g. wood comprises a drier (1), in which the fuel is dried by contact with superheated steam. The dried fuel is fed into a pyrolysis unit (4) to which superheated steam is also supplied. The volatile tar containing components produced in the pyrolysis unit (4) is passed to an oxidation zone (5) in which an oxidation agent is added so as to cause a partial oxidation, whereby the content of tar is substantially reduced. The solid fuel components from the pyrolysis unit (4) may be fed into a gasification unit (6) to which hot gases from the oxidation zone (5) are supplied. In the gasification unit (6) the solid fuel components are gasified or converted to carbon. The gas produced in the gasification unit (6) may be burnt in a combustion unit (7), such as a combustion engine. Thus, a gasification process is obtained for gasification of biomass and waste with a high energy efficiency, low tar content of the gasification gas, with moderate risk of slagging for a wide spectrum of fuels, including fuels with a large content of moisture.
A method and a system for decomposition of moist fuel or other carbonaceous materials

The present invention relates to a method and a system or installation for decomposition, gasification and/or combustion of moist fuel or combustible organic or carbonaceous materials, such as special waste fractions or biomass, e.g. wood chips, wood pellets or a combination of any such different fuels.

It is well known to produce gas and activated carbon from solid fuels. In case of thermal gasification of such fuels with large water content, e.g. wood chips or waste, pre-drying of the fuel is generally used to obtain high-energy efficiency. Such pre-drying may be performed by adding superheated steam to the fuel. Thus the steam absorbs further moist.


The present invention provides an improved method and an improved system or installation of the above type. Thus, the present invention provides a method for decomposing moist fuel or combustible organic material, said method comprising heating the fuel at separate stages, including a drying stage, a pyrolysis stage to which steam is supplied, an oxidation stage, and a gasification and/or combustion stage, to temperatures causing the fuel to decompose into gaseous and solid components, the fuel at the various stages being at least mainly heated by means of the gases formed by the oxidation, gasification and/or combustion processes. Preferably, volatiles from the pyrolysis are subsequently partially oxidized at the oxidation stage prior to being transferred to the gasification stage.
One of the larger technical problems in decomposition of combustible organic material or carbonaceous material is that the volatile products or gases produced contain an undesired content of tar, which tar condenses when the gases are cooled. By dividing the decomposition process into separate stages comprising pyrolysis with steam, partial oxidation, and gasification it is possible to obtain a rather small content of tar in the exhaust gases produced, and the method according to the invention may be used for decomposition of carbonaceous material in a large scale, since the internal heat transfer overcomes the limitations in up scaling known from externally heated reactors.

In the pyrolysis stage the solid organic fuel is typically heated to a temperature between 300°C and 800°C and decomposed into a solid component and a gaseous component containing tar. In the oxidation stage air or another oxygen containing gas is supplied so as to cause a partial oxidation. Thereby the temperature may be increased to for example 1000°C – 1300°C, and most of the large tar molecules are decomposed into smaller gaseous molecules. Finally, in the gasification stage the hot exhaust gases from the oxidation stage are used to gasify the solid components, and the tar content of the gaseous phase or component is further reduced when contacting the solid phase or component of the material being processed.

A number of advantages are obtained by adding steam to a thermal gasification process, such as the pyrolysis stage. Such advantages comprise: lower process temperatures, higher char conversion, smaller production of particles, and presumably lower emissions of NOx, CO and UHC at the subsequent combustion.

Further advantages are

- A relatively simple and robust cleaning of gas due to the low tar content.
- A stable process even in fluid bed layout: Pyrolysis reaction times of about 1-5 minutes in a fluid bed layout results in a stable gasification process even when the feeding rate is varying.
Compact pyrolysis reactors: Both moving bed and fluid bed pyrolysis reactors can be designed in more compact ways than of known stage divided gasification processes.

- Small and few parts (partial oxidation stage) with temperatures around 1000°C.

- Clean flue gas, which may be used for district heating in condensing mode without condensate cleaning.

Other gasification reactors, in which pyrolysis and gasification take place, must be made from materials, which are able to resist very high temperatures, because such high temperatures may occur all over in the reactor. Therefore, it is advantageous to divide the process into stages so that the high temperatures occur in only some of these stages.

The method according to the invention may take advantage of the fact that the tar content in a hot gas (500-1000°C) is reduced when passing through partially gasified char, and that activated carbon can be produced by pyrolysis with steam and by gasification with steam and CO2 as gasification means. The use of steam, that can be condensed during gas conditioning, will increase the heat value of the gas compared with other gasification agents.

Originally, the fuel or organic material to be processed by the method according to the invention usually contains more or less moisture, and in such case the fuel is preferably dried before being passed to the pyrolysis stage. Such drying may be performed in any manner, at a location or stage remote from the location of the other stages, and heated steam may then be supplied to the pyrolysis stage from another steam source, such as a steam source located adjacent to the pyrolysis stage.

In the preferred embodiment, however, the fuel is dried at a location adjacent to the pyrolysis stage. Thus, the moist fuel may be dried in a drying unit by contacting it with superheated steam, the dried fuel being transferred to the pyrolysis stage, where it is further heated and decomposed into solid and gaseous components, at least some of the steam having been used for drying the fuel in the drying unit being also used for further heating at the pyrolysis stage and/or in a subsequent processing stages.
Steam supplied to the drying unit and/or the pyrolysis stage may be superheated mainly by gasification gas and/or heat generated by oxidation of fuel components.

5 The fact that sensible heat from the gasification gas or from the attached combustion stage may be recovered and used for drying, pyrolysis and preheating of combustion and/or gasification air means that a high energy efficiency may be obtained by using the method according to the invention. When using sensible heat from the gasification or combustion stage for pyrolysis, a high outlet temperature is required (normally 500-800°C).

In a stage divided gasifier, the heat transfer to the pyrolysis process normally takes place by indirect heat transfer from the combustion stage through the outer external limits of the pyrolysis stage or unit. Thus, there are geometric limitations to up scaling of the pyrolysis reactor. This problem is overcome by this new invention where heat namely is transferred internally in the reactors in combination with external heat exchangers.

In other downstream thermal gasification processes, the ashes may agglomerate and melt together at relatively low temperatures, which may cause closing down of the reactors. This problem is overcome by this new invention by having only a limited zone of high temperature followed by endothermic steam gasification.

The method according to the invention may be used in high-grade thermal gasification of the fuel or organic material, which comprises specific waste fractions or biomass, such as wood chips or a combination of various other fuels. Then, the method may comprise supplying one or more of said fuels to a drying unit, in which the fuel is dried by contacting it with superheated steam supplied from a super heater so as to provide dried fuel, transferring the dried fuel to the pyrolysis stage, heating outlet steam/gas from the drying unit in a super heater supplying the superheated outlet steam/gas to the pyrolysis stage and/or another of the process stages, and supplying steam and volatiles from pyrolysis products there from to a first succeeding process stage, in which the volatile pyrolysis products are at least partially oxidized by adding an oxidizing agent, such as atmospheric air or oxygen.
The outlet steam/gas supplied to the pyrolysis stage may be heated in a super heater by product gas from the gasification stage and/or combustion gas from the combustion stage.

The products from said first succeeding process stage may be led to the next succeeding process step, where they react with the solid part of the product mass from the pyrolysis stage and generate gas and possibly particles, a char residue and/or ashes. The gas from this next process stage may wholly or partially together with one or more oxidation agents be led to a combustion unit where oxidation of the added tar/gases takes place.

The present invention provides a process for gasification of solid fuels with relatively high water content. The size of a plant for performing such a process may vary from 1 to about 250 MW input effect. The gasification process enables high-energy efficiency, a low tar content in the gas, takeout of activated carbon, low environmental impact in the form of emissions and condensates, even though the flue gas temperature from the combustion unit is relatively low. Because the method is divided into stages the parts of the reactors that have to be made from very temperature resistant materials can be reduced considerably. At the same time, the possibility of avoiding melting and agglomerating of ashes is increased.

This is due to the fact that according to the invention the gasification process is divided into the following stages: drying (if necessary), pyrolysis (where superheated steam is used as heating means), partial oxidation, gasification and combustion. Further, the high-temperature heat from the gasification gas and the flue gas can be utilised for the drying and pyrolysis stages. In practice, the different process stages may be connected or combined in different ways, e.g. drying and pyrolysis in the same reactor or pyrolysis, partial oxidation and gasification in an integrated reactor. This depends on the practical detailed design of the various components and the fuel used, including the humidity of the fuel.

As previously mentioned, according to a preferred embodiment the fuel is dried by means of superheated steam. The superheated steam may be circulated through the fuel and a
heat exchanger. In the heat exchanger, energy is added to superheat the steam. When the superheated steam is contacted with the fuel, heat is transferred from the steam, and moisture from the fuel is absorbed in the steam. The dried fuel is transferred to the pyrolysis stage, and the outlet steam is superheated to a high temperature (e.g. 450-800°C) and supplied to the pyrolysis stage, in which the dried fuel is pyrolysed. In an oxidation stage or unit, in which the tar and combustible gasses are partially oxidized an oxidizing agent is added to the volatile components from the pyrolysis stage or unit. The heated gasses and the char are led to a gasification unit or zone where the char is gasified. The evaporated moisture from the fuel or biomass may be superheated to a high temperature by heat exchange with the produced gasification gas and/or by heat exchange with flue gases from the combustion unit. Similarly, the circulating steam, which is used for drying, may be superheated by heat exchange with the produced gasification gas and/or by heat exchange with flue gases from the combustion unit.

In a specific embodiment further energy is supplied to the pyrolysis stage from the stage at which the partial oxidation takes place, for example as radiation, or from the gasification unit, for example as re-circulation of char or bed material. Thereby high pyrolysis temperatures and, consequently, an efficient degasification of the fuel are obtained.

In a specific embodiment, in addition to the products from the partial oxidation, superheated steam is also supplied to the gasification unit, possibly mixed with another gas. The conversion of char at the gasification stage or unit at a certain temperature is thereby improved, and the activation of the char will also be improved.

According to the invention the solid fuel components may be passed from the pyrolysis unit to the gasification unit such that all of or part of said solid components is passed through the processing stage or unit for partly oxidizing volatile pyrolysis products, or such that said processing unit is completely by-passed.

Furthermore, carbon may be taken out from the pyrolysis stage or unit to be used as activated carbon, for example for purifying condensate generated by cooling gasification gas or flue gas. A condensate free from i.a. organic compounds may then be obtained, whereby the condensate may be disposed of with limited environmental impact.
According to a specific embodiment of the invention carbon may also be taken out from
the pyrolysis stage or unit or from the gasification unit and used as activated carbon for
purifying the gasification gas. In this way, undesirable, mainly organic compounds can be
removed from the gas.

The present invention further provides a system or plant for decomposing fuel or
combustible organic material, and the system comprises a pyrolysis unit or a similar
processing unit adapted to heat and decompose the fuel into solid and gaseous
components, means for supplying superheated steam to the pyrolysis unit to further heat
the fuel therein.

The fuel or carbonaceous material used in the plant or system may be dry, such as pellets
of wood, which have been dried and produced in a different plant and at another location.
Preferably, however, moist fuel may be used, and the system or plant according to the
invention may comprise a drying unit for drying the fuel by contacting it with superheated
steam before the fuel is passed into the pyrolysis unit, said means for supplying
superheated steam to the pyrolysis unit comprising connecting conduits for supplying at
least part of the steam having been used for drying the fuel in the drying unit to the
pyrolysis unit. When the fuel is heated and dried by means of superheated steam, in
which the content of oxygen is very low, fire hazard may be considerably reduced or
eliminated.

Preferably, the system further comprises at least one further processing unit arranged
downstream of the pyrolysis unit, means for supplying steam and volatile pyrolysis
products from the pyrolysis unit to said at least one further processing unit, and means for
adding an oxidizer, such as air or another oxygen containing gas, to the volatile pyrolysis
products so as to at least partly oxidize the same. Said at least one further processing unit
may comprise, for example, a gasification unit having transporting means for transferring
solid fuel components from the pyrolysis unit to the gasification unit, which is adapted to
heat and further decompose the solid fuel components supplied thereto, and an oxidation
unit adapted to at least partly oxidize gaseous fuel components supplied from the
pyrolysis unit, means being provided for transferring at least part of the heat energy generated by the oxidation process to the fuel components in the gasification unit.

As an example, the system or plant according to the invention may be used for high-grade thermal gasification of special waste fractions or biomass, e.g. wood chips or a combination of different fuels. The system or plant may comprise at least one steam generator (drying unit or evaporator), a super heater to superheat the generated steam, a pyrolysis unit to which preferably superheated steam and dried fuel is fed, and in which the fuel is decomposed into a gaseous and a solid fraction, an oxidation unit, in which a gaseous fuel component generated in the pyrolysis unit is partially oxidized whereby the tar content thereof is considerably reduced, and a gasification unit, in which solids from the pyrolysis reactor are gasified, and in which the tar content is further reduced due to contact between gas and solids. The system or plant may further comprise one or more of the following: Gas cooling devices in order to utilise the sensible energy in the gas, gas cleaning equipment for removing particles from the gas, and/or combustion devices e.g. engines or turbines for utilising chemical energy of the gas or devices for utilising the gas for producing other products.

A gasification plant for exploitation of the invention may be established by combining the drying unit, the pyrolysis unit, the partial oxidation zone and the gasification unit in one or more units. Otherwise, the plant could be constructed in compact form of modules and external heat exchangers.

Various embodiments of the system or plant according to the invention will now be further described with reference to the drawings, wherein

Fig. 1 diagrammatically illustrates how the basic processing units of the plant according to the invention may be interconnected,

Fig. 2 diagrammatically illustrates an embodiment, in which the pyrolysis unit is in the form of a screw conveyor, and in which the gasification unit is of the moving bed type producing gas for use in a gas engine,
Fig. 3 diagrammatically illustrates a preferred embodiment, wherein the pyrolysis unit and/or the gasification unit are of the moving bed type, and wherein the gas produced is used in a gas engine.

5 Figs. 4 and 5 diagrammatically illustrate embodiments, in which the pyrolysis and gasification units are integrated, and in which the gas produced is used in a gas engine, gasturbine or other combuster unit, and

Fig. 6 diagrammatically illustrates an embodiment, in which the pyrolysis and gasification units are pressurised and integrated, and in which the gas produced is used in a gas turbine.

Figure 1 diagrammatically shows a plant according to the invention having a drying unit or dryer 1 to which a bio fuel or waste is fed, a pyrolysis unit 4 to which dry fuel is supplied from the dryer 1, an oxidation unit, in which gaseous components from the pyrolysis unit 4 is partly oxidized, a gasification reactor 6, in which solid fuel components from the pyrolysis unit 4 is gasified, and a combustion unit 7 for finally oxidizing or burning the gaseous components.

20 In the dryer 1 the fuel is dried by superheated steam transferring energy to the fuel. Thereby the steam is cooled and will absorb moisture from the fuel. The steam is superheated in a super heater 2 and part of the steam is re-circulated to the dryer 1. The source for heat to be supplied to the super heater 2 may, for example, be flue gases from the combustion unit 7 or the hot product gas from the gasification reactor or unit 6. The remaining part of the steam is led to a steam super heater 3, in which the steam is superheated to about 500-800°C. The source for the heat supplied to the super heater 3 may also be heat product gas from the gasification reactor 6 or exhaust or flue gas from the combustion unit 7. The superheated steam is led to the pyrolysis unit 4, which may also be heated by other heat-sources. In the pyrolysis unit 4 fuel and steam will be mixed and thereby the temperature of the fuel will rise and the fuel will decompose into a solid fraction and a gaseous tarry fraction or volatiles. The volatiles are led to the oxidation unit 5, in which an oxidation agent, e.g. air, is added to cause a partial oxidation of the tar containing volatiles. In this oxidizing process the long molecular and condensable tars will
decompose into smaller molecules that are less condensable. Furthermore, the
temperature in the gasification unit 5 increases to about 1000-1300°C. The combustion
products from unit 5 and the solid fuel component from the pyrolysis unit 4 are led to the
gasification reactor or unit 6, in which the carbon part is wholly or partially gasified. A solid
fraction can be taken out separately or together with the produced gas, which is cooled
and cleaned in a cleaning device and finally burnt in the combustion unit 7.

If the system or plant shown in Fig. 1 is used for processing dry fuels, such as wooden
pellets, the dryer or drying unit 1 may be dispensed with and replaced by an evaporator or
steam generator (not shown) to generate steam, which is supplied to the pyrolysis unit 4.
The heat source used for the super heater 2 may also be used for the evaporation of
water in the steam generator.

Figure 2 diagrammatically shows an embodiment of the system according to the
invention, which in principle corresponds to the system or plant shown in Fig. 1. In the
embodiment of Fig. 2 each of the drying and pyrolysis units is in the form of a screw
conveyor 1 and 4, respectively, arranged such that the outlet end of the screw conveyor 1
forming the drying unit is communicating with and is discharging into the inlet end of the
screw conveyor 4 forming the pyrolysis unit. The screw conveyor 4 discharges into the
gasification reactor 6, which is of the moving bed type, and gas from the reactor 6 is
supplied to combustion unit in the form of a combustion engine 7.

The moist fuel fed into the drying unit 1 is dried by means of superheated steam, which is
heated in a super heater in the form of a heat exchanger 2, by exhaust gas from the
engine 7. The dryer or screw conveyor 1 is preferably sloping upwardly towards the screw
conveyor or pyrolysis unit 4 at an angle of 25-35° with horizontal in order to increase
mixing of the fuel, to increase the contact between the fuel and superheated steam, and
to lift the fuel to the level of the pyrolysis reactor 4. The pyrolysis unit or screw conveyor 4
is further heated externally by a super heater in the form of a jacket 3 surrounding the
screw conveyor 4. At the outlet end of the screw conveyor 4 opens into the upper end of
the gasification reactor, which also define an oxidation zone 5 through which the volatiles
and possibly also the char fraction from the pyrolysis unit 4 will flow. Preheated air and/or
steam is/are injected into the oxidation zone 5, in which a partial oxidation of the volatiles takes place.

The char expelled from the pyrolysis unit 4 is collected in the gasification reactor 6, where it forms a char bed on top of a grate. Hot gases from the oxidation zone 5 flow downwardly through the char bed and react with the char.

Since the gasification reactions taking place in the reactor 6 are endothermic the temperature in the char bed decreases down through the bed. At the top of the bed the temperature may be about 900-1000°C while the temperature of the char/ash at the grate is between 750-800°C.

The char bed also functions as a tar-filter, in which tar that has not been decomposed in the oxidation zone 5 adsorbs to the char. The product gas from the gasification reactor can be used in the heat exchangers for process integration. Following process steps are suggested depending on the moisture content of the fuel:

- Pyrolysis
- Air preheat
- Superheating of steam
- Evaporating of water (if dry fuels are used)
- District heating/other heating.

Since the particles are not sticky bag house filters are recommended as the gas-cleaning technology after cooling of the gas to about 100°C-200°C. Finally, the cooled and cleaned gas is led to a combustion unit, which may be the internal combustion engine 7.

In the embodiment illustrated in Figure 3 the pyrolysis unit 4 is either formed as a bubbling fluid bed, in which the steam acts as fluidising means as well as a heat source for the pyrolysis process, or as a moving bed, in which the fuel is slowly moved upwards when fuel is added at the bottom of the bed. The pyrolysis unit may contain an inactive bed material, e.g. sand or dolomite, to stabilise the flow and the temperature in the unit. The fuel is fed into the lower part of the pyrolysis unit 4 and is passed up through the bed, while the fuel is being heated and pyrolysed. From the upper part of the pyrolysis unit 4
pyrolysed fuel and gas are passed into the oxidation unit 5, where an oxidizing agent is added. The oxidation unit may have nozzles for adding the oxidizing agent, and these nozzles may be tilted so that they may also function as ejectors. The gasification unit 6 is a fixed bed reactor, in which the char forms a bed on a grate. The hot gases from the 5 oxidation unit 5 flow through the char bed, whereby the char is gasified and residual tar is caught in the bed. Solid material is removed, and the gas produced in the gasification reactor 6 is cooled in the super heater 3 by heat exchange with e.g. the exhaust steam from the dryer 1. The gas is further cooled for example by air pre-heating and/or production of district heating and/or evaporation of steam to be supplied to the heater 3. The cooled gas is burnt for example in the combustion engine 7, and the hot exhaust gases from the engine may be utilised for superheating steam in the super heater 2 for the steam supplied to the dryer 1.

Figure 4 diagrammatically illustrates an embodiment, in which the pyrolysis unit 4, the 15 oxidation unit 5 and the gasification unit 6 are integrated in a fluid bed reactor. In this reactor pyrolysis and gasification takes place in a pair of spaced fluid beds with a high temperature oxidation zone in between. In Figure 4, the pyrolysis unit is formed by a bubbling bed 4 at the bottom of the reactor. The hot oxidation zone 5 for partial oxidation is positioned above the pyrolysis zone 4, and at the top of the reactor the char particles are gasified in a circulating type fluid bed forming the gasification unit 6.

In the pyrolysis unit 4 the steam functions not only as fluidisation medium, but also as a heat carrier, while re-circulating char and sand are additional heat carriers. The re-circulating char can be gasified on its way to the pyrolysis zone or by adding some gasification media, such as steam and/or air to a re-circulation conduit interconnecting the upper end of the gasification unit 6 and the upper end of the pyrolysis unit 4. An oxidizing agent may be added to the oxidation unit 5, which between the pyrolysis unit 4 and the oxidizing unit 6 define a throttle. In this throttle the flow velocity of the gas increases thus preventing the char from running from the gasification unit or zone 6 to the pyrolysis unit or zone 4.

Figure 5 also diagrammatically illustrates an embodiment, in which each of the pyrolysis and gasification units are in the form a fluid bed reactor 4 and 6, respectively, and in which the gas produced is used for driving a gas engine, not shown. Dry fuel, which may
have been dried at some other location in any suitable manner, is supplied to the bottom part of the pyrolysis reactor 4 to which superheated steam is also fed from any suitable source, not shown. Volatiles produced in the pyrolysis reactor 4, in which the fluid bed is of the spouted type, are passed to the bottom part of the gasification reactor 6 via the oxidation unit 5, in which the volatiles are partially oxidized. In the embodiment shown in Figure 5 the bed materials and volatiles exhausted from the pyrolysis reactor 4 are separated in a cyclone. The volatiles are led to the oxidation unit 5 and the bed materials are led to the bottom part of gasification reactor 6. A throttle is formed between the oxidation unit 5 and the gasification reactor 6 so as to increase the velocity of the gas flow and thereby prevent material in the gasification reactor 6 from running down into to the lower positioned oxidation unit 5. Bed materials and gas exhausted from the gasification reactor 6 are separated in a wear resistant cyclone. The product gas is led to gas cleaning and cooling steps, and the bed materials are led to the bottom part of the pyrolysis reactor 4, whereby the temperature therein may be increased.

In the embodiment diagrammatically illustrated in Figure 6 the pyrolysis zone 4, the oxidation zone 5, and the gasification zone 6 are integrated in a pressurised reactor as vertically spaced zones, and the zones 4 and 6 are of the fluid bed type. The product gas produced is used for driving the combustion unit in the form of a gas turbine 7. The reactor containing the zones or units 4-6 is similar to the reactor shown in Figure 4. In the present embodiment, however, a pressure exceeding atmospheric pressure is maintained within the reactor. Dried fuel is fed into the pyrolysis unit or zone 4 under pressure. Furthermore, pressurised water is evaporated and fed to a superheater 3 and is thereafter passed into the pyrolysis zone 4 as superheated steam. Product gas from the gasification zone or unit 6 is separated from solid material in a cyclone and is thereafter cooled, cleaned and led to the gas turbine 7.

It should be understood that various modifications, combinations and changes of the embodiments described above could be made without departing from the scope and spirit of the claims of the present application.
CLAIMS

1. A method for decomposing moist fuel or combustible organic material, said method comprising heating the fuel at separate stages, including a drying stage (1), a pyrolysis stage (4) to which steam is supplied, an oxidation stage (5), and a gasification (6) and/or combustion stage (7), to temperatures causing the fuel to decompose into gaseous and solid components, the fuel at the various stages being at least mainly heated by means of the gases formed by the oxidation, gasification and/or combustion processes.

2. A method according to claim 1, wherein volatiles from the pyrolysis are subsequently partially oxidized at the oxidation stage (5) prior to being transferred to the gasification stage (6).

3. A method according to claim 1, wherein the drying stage is performed at a location remote from the location of the other stages, heated steam being supplied to the pyrolysis stage from another steam source.

4. A method according to claim 1, wherein the fuel is dried in a drying unit (1) by contacting it with superheated steam, the dried fuel being transferred to the pyrolysis stage (4), where it is further heated and decomposed into solid and gaseous components, at least some of the steam having been used for drying the fuel in the drying unit being also used for further heating at the pyrolysis stage and/or for heating or use in a subsequent processing stage.

5. A method according to any of the claims 1-4, wherein steam supplied to the drying unit (1) and/or the pyrolysis stage (4) is superheated mainly by gasification gas and/or heat generated by oxidation of fuel components.

6. A method according to any of the claims 1-5 for use in high-grade thermal gasification of the fuel or organic material, which comprises specific waste fractions or biomass, such as wood chips or a combination of various other fuels, said method comprising
supplying one or more of said fuels to a drying unit (1), in which the fuel is dried by contacting it with superheated steam supplied from a super heater (2) so as to provide dried fuel,

transferring the dried fuel to the pyrolysis stage (4),

heating outlet steam/gas from the drying unit in a super heater (3)

supplying the superheated exhaust gas to the pyrolysis stage (4) and/or another of the process stages, and

supplying steam and volatiles from the pyrolysis stage to a succeeding process stage (5), in which the volatile pyrolysis products are at least partially oxidized by adding an oxidizing agent, such as atmospheric air or oxygen.

7. A method according to claim 6, wherein the exhaust gas supplied to the pyrolysis stage (4) is heated in a super heater (3) by product gas from the gasification stage (6) and/or combustion gas from the combustion stage (7).

8. A method according to claim 7, wherein the process energy necessary for the pyrolysis stage (4) is provided by the superheated steam/gas, possibly supplemented by energy from a partial oxidation stage (5), for example in the form of radiation, and/or supplemented by energy from the gasification stage, for example in the form of feed back of char, gas or bed material.

9. A method according to any of the claims 6-8, wherein the steam supplied to the drying unit (1) from the super heater (2) is heated by product gas from the gasification stage (6) and/or by combustion gas from the combustion stage (7).

10. A method according to any of the claims 6-9, wherein superheated exhaust gas, possibly mixed with another gas, is used as gasification medium, for example at the gasification stage.
11. A method according to any of the claims 1-10, wherein solid components from the pyrolysis stage is passed to the gasification stage totally or partially via a stage at which the volatile pyrolysis products are partially oxidized.

5 12. A method according to any of the claims 1-11, wherein steam activated char is withdrawn from the pyrolysis stage and/or the gasification stage to be used in purifying gas produced.

13. A system or plant for decomposing fuel or combustible organic material, said system comprising:

- a pyrolysis unit (4) or a similar processing unit adapted to heat and decompose the fuel into solid and gaseous components, and
- means (3) for supplying superheated steam to the pyrolysis unit to further heat the fuel therein.

15

14. A system according to claim 13, further comprising a drying unit (1) for drying the fuel by contacting it with superheated steam before the fuel is passed into the pyrolysis unit (4), said means (3) for supplying superheated steam to the pyrolysis unit comprising connecting conduits for supplying at least part of the steam having been used for drying the fuel in the drying unit to the pyrolysis unit.

15. A system according to claim 13 or 14, further comprising at least one further processing unit (5-7) arranged downstream of the pyrolysis unit (4), means for supplying steam and volatile pyrolysis products from the pyrolysis unit to said at least one further processing unit (5-7), and means for adding an oxidizer, such as air or another oxygen containing gas, to the volatile pyrolysis products so as to at least partly oxidize the same.

16. A system according to claim 15, wherein said at least one further processing unit comprises a gasification unit (6) having transporting means for transferring solid fuel components from the pyrolysis unit (4) to the gasification unit, which is adapted to heat and further decompose the solid fuel components supplied thereto, and an oxidation unit (5) adapted to at least partly oxidize gaseous fuel components supplied from the pyrolysis.
unit, means being provided for transferring at least part of the heat energy generated by the oxidation process to the fuel components in the gasification unit.

17. A system according to any of the claims 14-16, further comprising a super heater (3) for heating the steam or gas being supplied to the pyrolysis unit (4) from the drying unit (2).

18. A system according to claim 17, wherein the super heater (3) for heating the steam or gas supplied to the pyrolysis unit (4) is heated by product gas supplied from the gasification unit (6) and/or exhaust gas from a turbine and/or combustion gas from a combustion unit (7).

19. A system according to any of the claims 13-18, further comprising a super heater (2) for heating the steam supplied to the drying unit (1) and means for supplying product gas from a gasification unit (6) and/or combustion gas from a combustion unit (7) to the super heater so as to heat the steam passing there through.

20. A system according to any of the claims 16-19, wherein the transporting means are adapted to pass the solid fuel components from the pyrolysis unit (4) to the gasification unit (6) in such a manner that all or part of said solid components is passed through the oxidizing unit (5) for oxidizing volatile pyrolysis products, or such that the oxidizing unit is completely by-passed.

21. A system according to any of the claims 13-20, wherein the pyrolysis unit (4) and/or gasification unit (6) comprises a takeout for taking out steam activated char.

22. A system according to any of the claims 14-21, wherein the drying unit (1), the pyrolysis unit (4), a zone for partial oxidation (5), and a gasification zone (6) are forming a common entity or a plurality of interconnected units.
23. A system according to any of the claims 13-22 being formed by modules and external heat exchangers.

24. A system according to any of the claims 13-23, wherein the pyrolysis unit is in the form of a screw conveyor (4).

25. A system according to any of the claims 14-24, wherein the drying unit is in the form of a screw conveyor (19).

26. A system according to claim 24 or 25, wherein the screw conveyor is provided with an outer heating jacket (3), means being provided for feeding hot product gas to the jacket so as to heat the content of the screw conveyor.

27. A system according to any of the claims 13-23, wherein the pyrolysis unit and/or the gasification unit is /are in the form of a fluid bed.

28. A system according to claim 27, wherein the gasification unit and the pyrolysis unit are integrated in a common reactor, a gasification zone (6) being arranged spaced vertically above a pyrolysis zone (4), and an oxidation zone (5) being arranged there between.
Figure 1
Figure 6
### INTERNATIONAL SEARCH REPORT

**A. CLASIFICATION OF SUBJECT MATTER**

IPC7: C10J 3/84, C10J 3/20, C10J 3/06  
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)

IPC7: C10J, C10B, C01B  
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data have been consulted during the international search (name of data base and, where practicable, search terms used)

**WPI DATA, PAJ, EPO INTERNAL**

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>GB 2030273 A (HITACHI SHIPBUILDING &amp; ENGINEERING COMPANY), 2 April 1980 (02.04.80), figure 1, abstract</td>
<td>1</td>
</tr>
<tr>
<td>X</td>
<td>US 4614523 A (ADELINO H.F. SOARES), 30 Sept 1986 (30.09.86), figure 1, claim 1, abstract</td>
<td>1-2</td>
</tr>
<tr>
<td>Y</td>
<td>column 1, line 31 - line 37, abstract</td>
<td>3-6,9-10</td>
</tr>
<tr>
<td>Y</td>
<td>US 4284416 A (NICHOLAS C. NAHAS), 18 August 1981 (18.08.81), column 2, line 8 - line 15; column 2, line 19 - line 34; column 3, line 29 - line 40, figure, claims 1,3, abstract</td>
<td>3-6,9-10</td>
</tr>
<tr>
<td>A</td>
<td>figure, abstract</td>
<td>14,17-19</td>
</tr>
</tbody>
</table>

**X** Further documents are listed in the continuation of Box C.  
**X** See patent family annex.

---

**Date of the actual completion of the international search**  
6 June 2001

**Date of mailing of the international search report**  
27.06.2001

**Authorized officer**  
MARIANNE BRATSBERG/ELY

Telephone No.
<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>US 5439491 A (HELMUT KUBIAK ET AL), 8 August 1995 (08.08.95), figure 1, claim 1</td>
<td>13,21,23,27</td>
</tr>
<tr>
<td>Y</td>
<td>figure 1, abstract</td>
<td>24,26</td>
</tr>
<tr>
<td>Y</td>
<td>DE 3126049 A1 (HÖLTER, HEINZ), 13 January 1983 (13.01.83), figure 1, abstract</td>
<td>24,26</td>
</tr>
<tr>
<td>A</td>
<td>DE 3523765 A1 (GOE GESELLSCHAFT FÜR ÖKOLOGISCHE ENERGIETECHNIK MBH IN GRÜNDUNGS), 8 January 1987 (08.01.87), column 3, line 19 - line 24; column 3, line 30 - line 35; column 4, line 45 - line 58, column 5, line 7 - line 15, figure 1, claim 1, abstract</td>
<td>2,6,11-12, 15-16,20</td>
</tr>
<tr>
<td>Patent document cited in search report</td>
<td>Publication date</td>
<td>Patent family member(s)</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-----------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>GB 2030273 A</td>
<td>02/04/80</td>
<td>CH 641830 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 2934831 A,C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DK 160365 B,C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DK 379079 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FR 2436175 A,B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 1267796 C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 55038859 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 59040184 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SE 434273 B,C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SE 7907530 A</td>
</tr>
<tr>
<td>US 4614523 A</td>
<td>30/09/86</td>
<td>BE 901461 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR 6400043 U</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 3447100 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FI 850082 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO 850086 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SE 8500072 A</td>
</tr>
<tr>
<td>US 4284416 A</td>
<td>18/08/81</td>
<td>AU 532676 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AU 6534680 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR 8008128 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CA 1125026 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 3068327 D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 0030841 A,B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 56103290 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZA 8007818 A</td>
</tr>
<tr>
<td>US 5439491 A</td>
<td>08/08/95</td>
<td>AT 60931 T</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR 8707836 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CA 1286110 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 1017998 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 87107590 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 3635215 A,C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 3768091 D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 0329673 A,B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ES 2008269 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2500447 T</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2594590 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SU 1828465 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 5064444 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 5346515 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 8802769 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZA 8707783 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 4124281 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 5157912 A</td>
</tr>
<tr>
<td>DE 3126049 A1</td>
<td>13/01/83</td>
<td>NONE</td>
</tr>
<tr>
<td>DE 3523765 A1</td>
<td>08/01/87</td>
<td>NONE</td>
</tr>
</tbody>
</table>