METHOD OF GENERATING AN ENERGY SOURCE FROM A WET GAS FLOW

Inventors: Raymond Guyomarc’h, Saint Theodorit (FR); Bernard Weil, Paris (FR)

Correspondence Address:
GREER, BURNS & CRAIN
300 S WACKER DR, 25TH FLOOR
CHICAGO, IL 60606 (US)

Appl. No.: 12/441,230
PCT Filed: Sep. 13, 2007
PCT No.: PCT/FR07/01486
§ 371 (c)(1), (2), (4) Date: Mar. 13, 2009

Abstract

A method of generating energy from a gas flow, called the initial flow, including water vapour, the method including the deoxidation of at least some of the water vapour by passing the initial gas flow through a layer of material at high temperature, called the thermal base layer, essentially including high-temperature carbon, the deoxidation making it possible to obtain a first gas flow comprising hydrogen obtained by the reaction of the water vapour with the carbon elements. The initial flow may be a gas flow that has served for the treatment of a charge of wood. The hydrogen obtained constitutes an energy source and may then be used to produce energy by a gas boiler, a gas turbine, a fuel cell, a gas-powered engine, a turbogenerator, or the like.
METHOD OF GENERATING AN ENERGY SOURCE FROM A WET GAS FLOW

[0001] The present invention relates to a method of generating a renewable energy source from a gas flow and the use of this energy source to produce electricity with a high yield. It also relates to a system implementing the method according to the invention.

[0002] The field of the invention is the field of generation of an energy source. The invention applies more particularly to generation of an energy source from a gas flow, comprising steam and having served in any treatment, or produced by any method or system.

[0003] There are currently numerous systems producing gas flows for energy purposes, in particular from water or steam. Most of these methods and systems utilize complex reaction techniques which require various supplies of energy and raw materials, downstream and upstream of the reaction. These methods and systems must most often be used somewhere other than where the product of the reaction is operated. This energy source is, in most cases, used to produce a thermodynamic gas flow, which is generally steam, producing mechanical work or electricity.

[0004] However, these methods and systems allow recovery of only some of the thermal energy from the gas flow comprising steam. Furthermore, the yield from these methods and systems is not very high. For example, in most of the methods and systems currently known, the electricity production yield does not exceed 60%. These methods and systems suffer substantial losses which reduce their attractiveness.

[0005] A purpose of the invention is to propose a method and a system allowing an energy source to be generated from a gas flow comprising steam with a better yield than the current methods and systems.

[0006] Another purpose of the invention is to propose a method and a system which make it possible to more easily generate an energy source from a gas flow.

[0007] The invention proposes to deal with the abovementioned problems by a method of generating energy from a so-called initial gas flow, comprising steam, the method comprising deoxidation of at least some of the steam by passing the initial gas flow through a layer of high-temperature oxidation-reduction material, called the thermal base, essentially comprising high-temperature carbon elements, the deoxidation making it possible to obtain a first gas flow comprising hydrogen obtained by the reaction of the steam with the high-temperature carbon elements.

[0008] The method according to the invention makes it possible to generate hydrogen from the steam present in the initial gas flow, using high-temperature carbon elements. The hydrogen generated is the energy source, which represents a very substantial energy value. The method according to the invention makes it possible to recover not only a large part of the thermal energy from the steam present in the initial flow, but also a large part of the deoxidation energy of the H₂O molecule by the generation of hydrogen from this steam. Thus, for a given quantity of steam, the method according to the invention makes it possible to generate more energy than the current methods and systems. Furthermore the hydrogen, vector of this energy, can be used in numerous known industrial systems.

[0009] The initial gas flow can comprise steam from an industrial method at the installation site, from the recycling of the steam after combustion of the hydrogen, or thermomechanical means vaporizing a volume of water during the start-up of the system.

[0010] In the method according to the invention, the thermal base essentially comprises high-temperature carbon elements and makes it possible to provide, in a single system, the thermal energy and the carbon elements for carrying out the deoxidation of the steam and producing H₂. The carbon elements can be those of the chemical composition of the known raw materials such as coal, lignin, peat, vegetable or animal biomass.

[0011] Advantageously, taking account of the exploitable energy value of the generated hydrogen and the energy used to generate this hydrogen, the method according to the invention makes it possible to achieve an exploitable energy yield greater than that of the current methods and systems.

[0012] In the method according to the invention the thermal base comprising high-temperature carbon makes it possible on the one hand to raise the temperature of the steam contained in the initial flow in order to create the temperature necessary for the deoxidation of this steam, and on the other hand to provide the carbon elements which are involved in this deoxidation. The temperature at the thermal base is such that the steam passing through this thermal base reacts with the high-temperature carbon elements so as to produce hydrogen by the following deoxidation reactions:

C+H₂O→CO+H₂, endothermic reaction (~131 kJ)

CO+H₂O→CO₂+H₂, exothermic reaction (~46 kJ)

[0013] The balance of the above deoxidation reactions is therefore:

C+2H₂O→CO₂+2H₂, endothermic reaction (~91 kJ)

[0014] This reaction therefore requires a heat supply of 91 kJ in order for the disproportionation, formulated above, to be achieved. This energy is provided by the combustion of at least some of the thermal base.

[0015] The method according to the invention can also comprise a step separating the hydrogen from the other elements contained in the gas flow after deoxidation of the steam. This separation can be carried out by devices available in the trade.

[0016] Advantageously, the method according to the invention can comprise storage of the hydrogen obtained during the separation stage.

[0017] Advantageously, the method according to the invention can comprise generation of electricity in a fuel cell from at least some of the hydrogen, this generation also producing a reaction gas. The reaction gas essentially comprises steam which can be recycled and deoxidized through the thermal base in order to produce hydrogen which will again serve to generate electricity in the fuel cell, in a continuous cycle.

[0018] The method according to the invention can also advantageously comprise combustion of at least some of the hydrogen in a gas-fired boiler, said combustion producing thermal energy and a combustion gas comprising high-temperature, low-pressure steam. The combustion of the hydrogen can also be carried out in a gas turbine, a gas engine, or a conventional boiler producing steam.

[0019] In an embodiment of the method according to the invention, the combustion of the hydrogen in the steam boiler can be carried out under O₂. In this embodiment, the combustion gas flow comprises virtually only very high-temperature, low-pressure steam.
In a second embodiment of the method according to the invention, the combustion of the hydrogen can be carried out under air.

In a second embodiment of the method according to the invention, the combustion of the hydrogen can be carried out under air.

Advantageously, at least some of the thermal energy produced by the combustion of the hydrogen can be used to condition a thermodynamic fluid in a second gas flow essentially comprising high-temperature, high-pressure steam.

At least some of the high-temperature, high-pressure steam can also be used in a system for the production of mechanical and/or electrical energy.

Advantageously, at least some of the steam contained in the second gas flow is used to produce electricity in a steam turbine, or a turboalternator, this production of electricity also comprising generation of a third gas flow comprising low-pressure, low-temperature steam. The temperature/pressure pairing that can be obtained in the system and method according to the invention can reach very substantial levels which make it possible to carry out electricity production at the highest yield of existing and future systems and to increase the electricity production yield relative to the thermal potential used at the start.

The method according to the invention can also comprise compression of at least some of the low-temperature, low-pressure steam contained in the third gas flow bringing said steam to a condensation pressure. This compression can be carried out in compression means arranged at the outlet from a steam turbine.

Advantageously, the method according to the invention can comprise recovery of at least some of the condensation energy of the steam obtained after compression.

The method can also comprise an increase in temperature of at least some of the steam contained in the third flow.

Advantageously, at least some of the steam contained in the combustion gas can be deoxidized by passing said steam through the thermal base. In fact the method according to the invention can comprise recycling of at least some of the combustion gas comprising steam, by passing at least some of this gas through the oxidation-reduction thermal base, for a fresh deoxidation of said steam in this gas, this deoxidation again producing hydrogen. The permanent recycling of the gas flows logically restores all of the energy potential that they contain less the losses inherent in the systems and equipment used for the invention. Therefore, all of the residual heat capacity of the steam can thus be recovered at the thermal base and is deducted from the energy to be provided to condition the oxidation-reduction carbon elements and allow the disproportionation or the deoxidation of the steam. The hydrogen obtained is again transferred to the energy cogeneration system, in a continuous cycle.

In this recycling mode, the thermal base must be capable of deoxidizing steam continuously, the quantity of high-temperature carbon must therefore be sufficient. The supply of high-temperature carbon must be continuous.

In a particular embodiment, at least some of the steam contained in the combustion gas can be mixed with at least some of the steam obtained in any peripheral system, such as a system for the dehydration of vegetable biomass or system for supplying water in liquid phase and evaporation in an exchanger using the surplus heat of the system according to the invention. The mixture can then be deoxidized through the thermal base and a fresh cycle started in the method according to the invention, in a continuous cycle.

Advantageously, at least some of the steam of the third flow, compressed to a condensation pressure then raised in temperature, can be recycled and used to produce electricity in a steam turbine, after a raising of its temperature and its pressure. The temperature of the steam can be raised using the thermal energy present at the thermal base or the thermal energy obtained by combustion of the hydrogen in a gas-fired boiler, or both.

Advantageously, the method according to the invention can comprise generation of the thermal base by combustion of vegetable biomass or of coal.

The combustion of biomass can be carried out under O₂ or under air.

The biomass the combustion of which makes it possible to generate the thermal base can comprise vegetable biomass, the moisture content of which has been reduced beforehand, such as biomass dried in air, biomass dried in a treatment unit, roasted biomass, etc.

Advantageously the initial gas flow can comprise at least some of a gas flow treating a biomass feedstock, such as the gas flow dehumidifying, drying or roasting a biomass feedstock. In this case, the steam present in the initial gas flow comes from the dried, dehumidified or roasted biomass.

The initial gas flow can comprise CO₂ or any other neutral gas that served as a heat-transfer vector for dehydration and treatment. However, as the thermal base comprises high-temperature carbon elements, it is preferable that the initial gas flow comprises CO₂. Furthermore, it is more advantageous for the initial gas flow to comprise CO₂ given that the separation of the hydrogen from the CO₂ is an operation known to a person skilled in the art and easily carried out.

After the separation of the hydrogen from the CO₂, at least some of the CO₂ can also pass through at least one heat exchanger in order to reach the temperature necessary for a predetermined treatment and be directly used in the treatment in question. The treatment in question can be the roasting, drying, dehumidifying, etc. of a wood feedstock for example.

Advantageously, after the separation of the hydrogen from the CO₂, at least some of the CO₂ can be condensed and recovered, for example in liquid phase.

The thermal base used in the method according to the invention can be burning at a temperature which is controlled by injecting oxygen into the core of said base. This injection of oxygen can serve to control the temperature at the core of the base, upstream of the base or downstream of the thermal base.

According to another feature of the invention, a system is proposed of generating energy from a so-called initial gas flow, comprising steam, the system comprising:

- means of generating a layer of high-temperature material, called the thermal base, essentially comprising high-temperature carbon;
- means for passing said gas flow through said thermal base, the passage allowing deoxidation of at least some of the steam, the deoxidation making it possible to obtain hydrogen by reaction of the steam with the carbon.

In a particularly advantageous version of the invention, the generation means comprise a heat generator provided to generate at least some of the thermal base, the generator also being provided to deoxidize at least some of the steam which passes through the thermal base. In fact, the thermal base can be located within the heat generator.
The heat generator can comprise a thermal reactor or solid-fuel furnace or also a hybrid device allowing the combustion of a solid fuel, in particular vegetable biomass, the moisture content of which has been reduced by prior treatment. This combustion produces high-temperature carbon elements at least some of which can be used to produce the thermal base, and used as high-temperature oxidation-reduction carbon.

Advantageously, the heat generator can be equipped with a system controlling the temperature of the walls, by circulation of a heat-transfer fluid. The generator can comprise double walls between which the heat-transfer liquid, for example pressurized water, can circulate. The heat-transfer liquid can also be projected onto the walls of the heat generator.

In a particular version of the invention, the heat generator can comprise a grating furnace provided to receive the thermal base and set up to transfer the combustion gases of a biomass feedstock producing at least in part the thermal base and the initial gas flow.

The grating furnace can advantageously be equipped with a system of cooling by circulation of a heat-transfer fluid in the grids of the furnace.

The heat generator can also comprise oxygen-injection means. The injection of oxygen can, on the one hand, serve to achieve the combustion of a solid fuel intended for the generation of the thermal base and on the other hand, to control the temperature at the thermal base.

The generator can also comprise means of collecting and separating the hydrogen obtained by deoxidation of the steam.

The heat generator can in particular comprise an expansion chamber for the gas flow that has passed through the high-temperature thermal base. This expansion chamber is used in particular to complete the disproportionation of the residual steam molecules to H₂ on contact with the carbon monoxide elements from the incomplete combustion of the high-temperature carbon.

Advantageously, the heat generator can comprise at least one heat exchanger, this heat exchanger being provided to carry out heat exchanges between the first gas flow, essentially composed of high-temperature CO₂ and H₂, and a heat-transfer fluid, which can be that of a cooling circuit for part of the heat generating system. This fluid is loaded with the thermal energy of said gas mixture in order to transfer it to an electricity cogeneration system, for example a turbo-alternator.

The system according to the invention can also comprise a device producing steam, valorizing the thermal energy from any element of the system.

The system can also comprise storage and/or distribution means for O₂ and/or CO₂.

Other advantages and characteristics will become apparent from examination of the detailed description of an embodiment which is by no means limitative, and the attached drawings in which:

FIG. 1 is a diagrammatic representation of a first embodiment of the method according to the invention using a steam boiler;

FIG. 2 is a diagrammatic representation of a second embodiment of the method according to the invention using a steam boiler;

FIG. 3 is a diagrammatic representation of a third embodiment of the method according to the invention using a fuel cell; and

FIG. 4 is a diagrammatic representation of a fourth embodiment of the method according to the invention using a fuel cell.

FIG. 1 diagrammatically represents a first embodiment of the method according to the invention. The system represented in FIG. 1 comprises a unit 1 storing a solid fuel comprising carbon, and more particularly combustible carbon. The combustible carbon can be coal or vegetable biomass the moisture content of which has been reduced by a prior treatment, such as dehumidification.

In the embodiment example represented in FIG. 1, the unit 1 is a unit storing a feedstock of combustible raw material with a high carbon content B₁. The feedstock of high-carbon combustible raw material B₂ is introduced, by a regulating system B, into the reactor R where it is burned under O₂. This combustible raw material is intended on the one hand to form the thermal base and on the other hand to bring this thermal base to, and maintain it at, the process temperature. The complete combustion of this raw material under O₂ produces CO₂.

The reactor R also receives an initial gas flow F₁ comprising high-temperature, low-pressure steam from an exchanger E₂ and a mixing box Cₘ. The steam from E₂ undergoes the oxidation-reduction reaction while passing through the thermal base. This disproportionation produces the high-temperature, low-pressure gas flow F₂. This first gas flow F₂ is composed essentially of H₂ and CO₂. H₂ and CO₂ are then separated in an industrial gas separation system S-G.

The CO₂ obtained by separation is a neutral gas flow Fₐ, too hot to be utilized as such, which is cooled in a cooling unit E₃. A part Fₐₐ of the cooled CO₂ is discharged and the remainder Fₐₕ compressed in compression means C₁ and stored in storage means S₁. A part Fₐₕ of the stored CO₂ can be used as a flow to cool the system according to the invention or for the safety of the system.

The hydrogen obtained is burned under O₂ in a gas-fired boiler Bₕ. The combustion of the hydrogen under O₂ makes it possible on the one hand to generate a very high-temperature combustion gas flow Fₖ essentially comprising low-pressure steam H₂O and on the other hand to generate a secondary gas flow F₉ essentially comprising high-temperature, very high-pressure steam. The combustion gas flow Fₖ, which has transferred the majority of its thermal potential to the secondary gas flow F₉, still retains a substantial thermal load at the outlet from the boiler Bₕ: approximately 10 to 20% of the calorific power of the combustion of H₂ under O₂ in the system. This combustion gas comprising steam is recycled into the reactor R after passing through an exchanger/mixing box E₂ and Cₘ where it can be mixed with a supply F₁₁ of liquid H₂O which serves as a top-up. The liquid H₂O is evaporated in the exchanger/mixing box E₂ and Cₘ, a system Pch coupled to a heating system for the start-up phase vaporizes the supplied water. The gaseous mixture thus formed, at the outlet from box Cₘ, becomes the initial gas flow F₁, it is at a high temperature and low pressure and participates in the useful heat exchange within the thermal base. All the thermal energy contained in this gaseous mixture is thus recycled, as
is the steam which is deoxidized again on passing through the thermal base, in a continuous cycle.

[0063] The second gas flow Fg2 comprising very high-pressure superheated steam obtained at the outlet from the gas-fired boiler Ch drives a steam turbine TAV which generates electricity by an alternator A coupled to the system. The turbine makes it possible to utilize most of the mechanical energy of the steam. At the outlet from the steam turbine TAV, a third gas flow Fg3 is obtained, comprising very low-pressure, low-temperature steam. This steam is compressed by a steam compressor C2, at a pressure sufficient for its physical change to the liquid state in the processor/exchanger VAP. The water obtained by condensation in this processor at the pressure relative to the enthalpy of the residual steam is superheated in the exchanger E1, it is thus recycled in thermodynamic flow Fth before being reintroduced into the secondary circuit of the gas-fired boiler Ch. A large part of the residual energy at the outlet from the steam turbine is thus recycled. The electricity necessary for the compression generates thermal energy, by the “Joule” effect, which is utilized by the system, thus neutralizing some of the effect of the electricity consumption of the compressor on the operating balance.

[0064] The continuous recycling of the steam in the disproportionation cycle and CO2 generates surpluses:

[0065] of CO2, Fn which is cooled in a cooling unit E3 (a part of or this CO2 is discharged into the ecosystem, the remainder Fn is compressed by compression means C1 and stored in storage means S1)

[0066] of H2O, the permanent recycling of the steam and the combustion of the thermal base can generate surplus steam, which will then be extracted from the recycling circuit.

[0067] FIG. 2 is a diagrammatic representation of a second embodiment of the method according to the invention. In this embodiment, the system according to the invention is used to recycle a gas flow Ft treating a biomass feedstock B1 and to valorize the energy from the gas flow that served to treat the biomass feedstock.

[0068] The biomass B1 is dehydrated or roasted in the treatment unit 1. After treatment, the extracted gaseous mixture comprises:

[0069] the treatment gas flow Ft, heat-transfer CO2, treating the biomass feedstock, and

[0070] steam from the initial biomass B1.

[0071] This gaseous mixture then becomes the initial gas flow F1 which is recycled in the system and method according to the invention.

[0072] A part B3 of the biomass B1 that has been treated, for example by roasting or drying, is stored. Another part B2 of the biomass B1 is introduced, by a regulating system B, into the reactor R where it is thermally reacted under O2 in order to form the thermal base some of which serves to bring this thermal base to, and maintain it at, the process temperature. Furthermore, the complete combustion of the biomass under O2 produces CO2 which can be used as heat-transfer flow Ft for the treatment of the original biomass B1.

[0073] The initial gas flow F1, comprising heat-transfer CO2 used in the treatment of the biomass B1 and the steam extracted from the original biomass, is recycled into the reactor R after a heat exchange in a heat exchanger E2 and passage through a mixing box Cm, explained below.

[0074] The initial gas flow is thus at a high temperature when it is introduced into the reactor R. The CO2 is neutral for the water-steam deoxidation reaction, but the steam under-
goes the oxidation-reduction reaction of the thermal base. This disproportionation produces a first gas flow Fg1 essentially comprising H2 and CO2. H2 is separated from the other components of the first gas flow, and in particular from the CO2, in an industrial gas separation system S-G, known to a person skilled in the art. The CO2 can be reused as heat-transfer gas Ft which will transmit its heat capacity to the biomass to be dehydrated or roasted. At the outlet from the separator S-G, the CO2, has transferred some of its thermal load into the exchanger E1. It may however still be too hot to be usable in treatment gas Ft, an injection of cold CO2 Fns will then regulate it. The hydrogen is burned under O2 in a gas-fired boiler Ch producing superheated steam with a very high yield. The combustion of the hydrogen under O2 makes it possible on the one hand to generate a combustion gas Gc1 essentially comprising high temperature/low-pressure steam H2O, and on the other hand to generate a second gas flow Fg2 essentially comprising steam by heating a thermodynamic fluid Fth essentially comprising water. At the outlet from the gas-fired boiler Ch, this second gas flow Fg2 essentially comprises high-temperature, very high-pressure steam. The combustion gas Gc1 which has transferred the greater part of its thermal potential to the second gas flow Fg2 still retains a substantial thermal load: 10 to 20% of the calorific power of the combustion of H2 under O2. The steam contained in the combustion gas is recycled into the reactor R after passing through the mixing box Cm where it will be mixed with the initial gas flow F1, i.e. with the gaseous mixture treating the original biomass: CO2+H2O from the dehydration of the biomass B1. The gaseous mixture thus formed becomes the new initial flow F1 which will be recycled into the reactor R, it is at a high temperature and participates in the useful heat exchange within the thermal base. All the thermal energy contained in this gaseous mixture is thus recycled. The steam is again deoxidized on passing through the thermal base, in a continuous cycle.

[0075] The second gas flow Fg2 comprising very high-pressure superheated steam, obtained at the outlet from the gas-fired boiler Ch, drives a steam turbine TAV which generates electricity using the alternator A coupled to the system. The turbine makes it possible to convert most of the “temperature/pressure” pairing of the steam into mechanical energy which will drive the alternator A. At the outlet from the steam turbine TAV, a third gas flow Fg3 is obtained, essentially comprising very low-pressure, low-temperature steam. This steam is then compressed by a steam compressor C2, to a pressure sufficient for its physical change to the liquid state in the processor VAP: the water obtained in this processor (at the pressure relative to the enthalpy of the residual steam) is superheated in the exchanger E1 before being reintroduced into the secondary circuit of the gas-fired boiler Ch. A large part of the residual energy at the outlet from the steam turbine is thus recycled. The electricity necessary for the compression generates thermal energy by the “Joule” effect which is utilized by the system, thus neutralizing some of the effect of the electricity consumption of the compressor on the operating balance.

[0076] The continuous recycling of the steam in the disproportionation cycle and CO2 generates surpluses. The surplus water is discharged into the ecosystem. The surplus CO2 Fns is cooled in a cooling unit E3. A part Fnr of this CO2 is discharged into the ecosystem, the remainder Fns is compressed by compression means C1 and stored in storage means S1.
FIG. 3 is a representation of a third embodiment of the method according to the invention using a fuel cell PAC. In the application example represented in FIG. 3, the unit 1 is a unit storing a feedstock of high-carbon combustible raw material B1. This raw material is a fuel for generating at the same time the physical and chemical conditions for the disproportionation of the steam contained in the initial gas flow. The fuel will preferably be solid, in order to create the best homogenization conditions for the H₂O disproportionation reaction.

The choice of fuel will be a combustible raw material which will preferably be renewable, i.e. dehydrated or roasted vegetable biomass, or peat or any other high-carbon fuel.

The feedstock of high-carbon combustible raw material B2 is introduced, by a regulating system B, into the reactor R where it is burned under O₂. The combustible raw material thus forms the thermal base, some of which serves to bring this thermal base to, and maintain it at, the process temperature. The complete combustion of this raw material under O₂ produces CO₂.

The reactor R also receives the initial gas flow F1 comprising high-temperature, low-pressure steam. The steam from the exchanger E1 undergoes the oxidation-reduction reaction while passing through the thermal base. This disproportionation produces a first gas flow Fg1 essentially composed of H₂ and CO₂ from the thermal reaction and the disproportionation. The first gas flow Fg1 is at a high temperature and low pressure. H₂ and CO₂ are separated in an industrial "gas separator" system S-G. The separator S-G can form an integral part of the fuel cell, of which it is then one of the constituents.

The CO₂ obtained from E1 is cooled in a cooling unit E3. A part Fp1 of the cooled CO₂ is discharged and the remainder Fp2 is compressed by compression means C1 and stored in storage means S1. A part Fp3 of the stored CO₂ can be used to cool the system according to the invention or for the security of the system.

The hydrogen obtained is introduced into the fuel cell PAC where it is chemically reacted by the physical means of the system and an injection of industrial O₂. This reaction makes it possible on the one hand to generate electricity with a very high yield relative to the energy potential used at the start and on the other hand to generate a reaction gas flow Fg2 essentially comprising high-temperature, low-pressure steam.

The electricity can be used directly by any conventional means.

The reaction gas flow Fg2 is therefore essentially composed of high-temperature, low-pressure steam which retains a substantial thermal load. This reaction gas flow Fg2 comprising steam is recycled into the reactor R after passing into an exchanger/mixing box E2 and Cm where it is mixed with a supply of liquid H₂O which serves as a top-up F1-1. The liquid H₂O is evaporated in the exchanger/mixing box E2 and Cm, a system Peh, coupled to a heating system for the start-up phase, vaporizes the supplied water.

The gaseous mixture thus formed, at the outlet from the mixing box Cm, constitutes at least in part the initial gas flow F1. This gaseous mixture is at a high temperature and low pressure and participates in the useful heat exchange within the thermal base. All the thermal energy contained in this gaseous mixture is thus recycled.

The steam is recycled into the reactor R, and is thus again deoxidized on passing through the thermal base, in a continuous cycle.

The continuous recycling of the steam in the disproportionation cycle generates surpluses:

- of CO₂ Fp (product of the disproportionation of H₂O by the thermal base, composed of carbon) which is cooled in a cooling unit E3. A part Fp1 of this CO₂ is discharged into the ecosystem, the remainder Fp2 is compressed by compression means C1 and stored in storage means S1.
- of H₂O, the permanent recycling of the steam and the combustion of the thermal base can generate surplus steam, which will then be extracted from the recycling circuit.

FIG. 4 is a representation of a fourth embodiment of the method according to the invention using a fuel cell PAC. In this embodiment, the system according to the invention is used to recycle a gas flow F1, treating a biomass feedstock B1 and the recycling (for the valorization of the energy and elements) of the gas flow that served to treat the biomass feedstock.

The biomass B1 is dehydrated or roasted in the treatment unit 1. After treatment, the gaseous mixture extracted comprises:

- the treatment gas flow F1, heat-transfer CO₂ treating the biomass feedstock B1, and
- steam from the initial biomass B1.

This gaseous mixture then becomes the initial gas flow F1 which will be recycled in the system and method according to the invention.

A part B3 of the biomass B1 that has been treated, for example by roasting or dry-drying, is stored. Another part of the biomass B2 is introduced, by a regulating system B, into the reactor R where it is thermally acted upon under O₂ in order to form the thermal base. Some of this biomass B2 serves to bring this thermal base to, and maintain it at, the process temperature. Furthermore, the complete combustion of the biomass under O₂ produces CO₂ which can be used as heat-transfer gas flow F1 to treat the original biomass B1.

The initial gas flow F1, comprising heat-transfer CO₂ used in the treatment of the biomass B1 and the steam extracted from the original biomass, is recycled into the reactor R after a heat exchange in a heat exchanger E1 and a passage through a mixing box Cm, explained below.

The initial gas flow F1 is thus at a high temperature when it is introduced into the reactor R. The CO₂ is neutral for the thermal reaction, but the steam undergoes the oxidation-reduction reaction of the thermal base. This disproportionation produces a first gas flow Fg1 essentially comprising H₂ and CO₂. H₂ is then separated from the other gaseous elements composing the first flow, and in particular the CO₂, into an industrial gas separation system S-G, known to a person skilled in the art.

The CO₂ can be reused as heat-transfer treatment gas flow F1 which will transmit its heat capacity to the biomass to be dehydrated or roasted. At the outlet from the separator S-G, the CO₂ has transferred some of its thermal load in the exchanger E1; it may however still be too hot to be usable in treatment gas F1, an injection of cold CO₂ Fin1 will then regulate it.

The hydrogen obtained is introduced into the fuel cell PAC where it is chemically reacted by the physical means of the system and an injection of industrial O₂. This reaction
makes it possible on the one hand to generate electricity in a very high yield relative to the energy potential utilized at the base and on the other hand to generate a reaction gas flow Fgr essentially comprising steam at a high temperature and low pressure.

[00100] The electricity can be used directly by any conventional means.

[00101] The reaction gas flow Fgr essentially comprises high-temperature, low-pressure steam which retains a substantial thermal load. This gas flow comprising steam is introduced into a mixing box Cm where it is mixed with the gas flow extracted from the unit 1 treating the biomass, and which has passed through the heat exchanger E1 where it has acquired a substantial heat capacity.

[00102] The gaseous mixture thus formed at the outlet from the mixing box Cm constitutes at least in part the initial gas flow F1 and is at a high temperature and low pressure and participates in the useful heat exchange within the thermal base. All the thermal energy contained in this gaseous mixture is thus recycled.

[00103] The steam is recycled and again deoxidized on passing through the thermal base, in a continuous cycle.

[00104] A part Fm of the CO₂ obtained is cooled in a cooling unit E3. A part Fm of the cooled CO₂ is discharged and the remainder Fm is compressed by compression means C1 and stored in storage means S1. A part Fns from the stored CO₂ can be used to cool the system according to the invention or for the security of the system. The surplus water is also discharged into the ecosystem at the outlet from the fuel cell PAC.

[00105] The CO₂, which will be used as heat-transfer treatment flow F1, is at a very high temperature at the outlet from the separator. It exchanges the greater part of its thermal load, with the gas flow extracted from the biomass treatment unit, in the exchanger E1. This heat-transfer flow will then be controlled, at the temperature necessary for its utilization, by a supply of cold CO₂ Fns1.

[00106] The invention is of course not limited to the examples which have just been described and can be used to generate energy from any gas flow comprising steam.

1-21. (Cancelled)

22. A method of generating hydrogen from a so-called initial gas flow essentially comprising steam and CO₂, said method comprising the following stages:

a first stage of deoxidation of some of the steam molecules with high-temperature carbon elements by passing said initial gas flow through a layer of high-temperature material, called the thermal base, essentially comprising high-temperature carbon elements, said deoxidation producing a synthesis gas flow comprising on the one hand hydrogen and carbon monoxide molecules generated by said deoxidation and, on the other hand, CO₂ and residual steam molecules originating from said initial gas flow, and

downstream of said thermal base, a second stage of deoxidation of said residual steam molecules in contact with said carbon monoxide molecules contained in the synthesis gas, said second deoxidation producing a first gas flow comprising on the one hand hydrogen and CO₂ originating from said deoxidation and CO₂ originating from the initial gas flow;

said thermal base being produced by combustion under O₂ of biomass the moisture content of which has been reduced.

23. The method according to claim 22, characterized in that the second deoxidation is caused by expansion of the synthesis gas flow in an expansion chamber.

24. The method according to claim 22, characterized in that it also comprises a step separating the hydrogen from the other elements contained in the first gas flow.

25. The method according to claim 24, characterized in that it also comprises storage of the hydrogen.

26. The method according to claim 22, characterized in that it comprises generation of electricity in a fuel cell from at least some of the hydrogen, said generation also producing a reaction gas comprising steam.

27. The method according to claim 26, characterized in that at least some of the steam contained in the reaction gas is recycled in order to be deoxidized again by passing said steam through the thermal base.

28. The method according to claim 22, characterized in that it also comprises combustion of at least some of the hydrogen in a gas-fired boiler, said combustion producing thermal energy and a combustion gas comprising high-temperature, low-pressure steam.

29. The method according to claim 28, characterized in that at least some of the thermal energy produced by the combustion of the hydrogen is used to condition a thermodynamic fluid in a second gas flow essentially comprising high-temperature, high-pressure steam.

30. The method according to claim 29, characterized in that at least some of the steam contained in the second gas flow is used to produce electricity in a steam turbine, said production also comprising generation of a third gas flow comprising low-pressure, low-temperature steam.

31. The method according to claim 30, characterized in that it also comprises compression of at least some of the low-temperature, low-pressure steam contained in the third gas flow bringing said steam to a condensation pressure.

32. The method according to claim 30, characterized in that it comprises recovery of at least some of the energy of condensation of the steam obtained after compression.

33. The method according to claim 31, characterized in that at least some of the steam is used to produce electricity in a steam turbine.

34. The method according to claim 28, characterized in that at least some of the steam contained in the combustion gas is recycled in order to be deoxidized again by passing said steam through the thermal base.

35. The method according to claim 28, characterized in that the combustion of the hydrogen is carried out under oxygen.

36. The method according to claim 28, characterized in that the combustion of the hydrogen is carried out under air.

37. The method according to claim 22, characterized in that it comprises an injection of oxygen into the core of the thermal base, said injection of oxygen being carried out so as to achieve incomplete combustion of the biomass, said incomplete combustion producing carbon monoxide molecules participating at least in part in the deoxidation of the steam molecules.

38. The method according to claim 22, characterized in that the initial gas flow comprises at least part of a gas flow treating a biomass feedstock.

39. A system comprising means for implementing the method according to claim 1.

* * * * *