

(43) International Publication Date
1 April 2010 (01.04.2010)

PCT

(10) International Publication Number
WO 2010/034748 A1(51) International Patent Classification:
C01B 3/08 (2006.01)(21) International Application Number:
PCT/EP2009/062334(22) International Filing Date:
23 September 2009 (23.09.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
MO2008A000249 26 September 2008 (26.09.2008) IT(71) Applicant (for all designated States except US): **UNIVERSITA' DEGLI STUDI DI MODENA E REGGIO EMILIA** [IT/IT]; Via Università, 4, I-41121 MODENA (IT).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **MILANI, Massimo** [IT/IT]; Via Buozzi, 145/1, I-41100 MODENA (IT). **MONTORSI, Luca** [IT/IT]; Via Settecani, 1146, I-41057 SPILAMBERTO (IT). **FRANZONI, Federica** [IT/IT]; Via Liguria, 7, I-42100 REGGIO EMILIA (IT).(74) Agent: **MODIANO, Micaela**; MODIANO GARDI PATENTS, Via Meravigli, 16, I-20123 MILANO (IT).

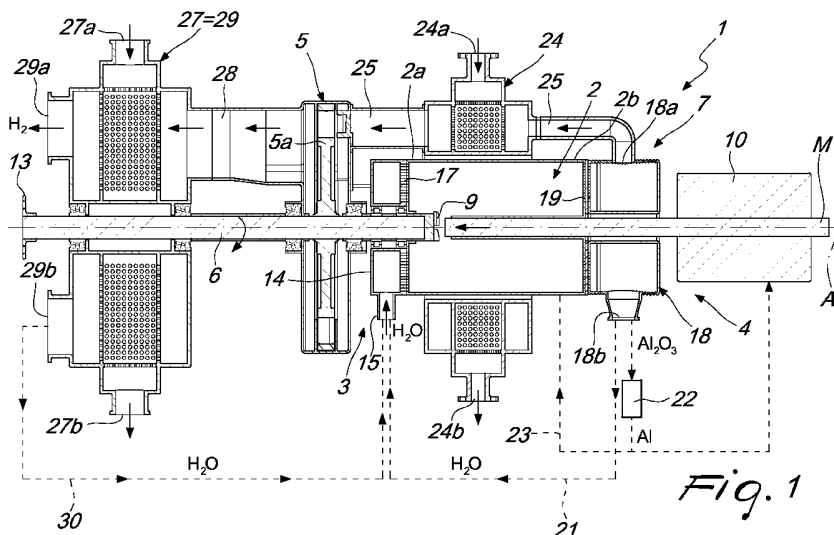
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: METAL-FUELED COGENERATION PLANT



(57) Abstract: A metal-fueled cogeneration plant (1), comprising at least one reaction chamber (2), means (3) for introducing at least one water-based liquid oxidizer, and means (4) for supplying at least one metal-based fuel into the chamber (2), the oxidizer and the fuel being adapted to give rise to an exothermic oxidation reaction to obtain gaseous hydrogen and at least one metallic oxide. The introduction means (3) are adapted to introduce in the chamber (2) a quantity of oxidizer that is substantially greater than the stoichiometric quantity to form steam and comprises at least one fluid-based motive power unit (5) that is fed in input by at least the steam for the rotary actuation of a driving shaft (6), separation and recovery means (7) for at least the steam being interposed between the chamber (2) and the inlet to the motive power unit (5), and means (8) for evacuation of the hydrogen being further provided.

METAL-FUELED COGENERATION PLANT

Technical Field

The present invention relates to a metal-fueled cogeneration plant.

Background Art

5 It is known that in view of the growing energy demand, the energy generation sector is constantly seeking innovative sources that have a low environmental impact and do not entail problems in the supply of fuels.

In this field, a research that uses the reaction of oxidation in water of metal fuels to generate hydrogen designed to supply engines such as fuel
10 cells has been developing for a long time, since hydrogen is a nonpolluting and renewable energy source. The metal fuels used to obtain this reaction are generally based on aluminum.

It is in fact known that pure aluminum in the solid/liquid state, in the presence of a water-based liquid oxidizer, develops, already in ambient
15 conditions, an oxidation reaction that rapidly reaches the temperature conditions required to maintain the optimum reaction:



According to the reaction of formula (1), also known as water splitting reaction, pure aluminum reacts with water to become gaseous
20 hydrogen and alumina in the solid and liquid state; this reaction is accompanied by the generation of heat (approximately 230 kcal per mole of Al), being highly exothermic.

The difficulty in the industrial application of the reaction (1) consists in that upon contact with air aluminum oxidizes, and therefore aluminum
25 articles become coated with a thin protective film that inhibits the reaction with water.

Various solutions have therefore been studied in order to render the aluminum inert with respect to air, in order to inhibit the formation of the oxide film, or to obtain the removal thereof directly in water, so as to allow
30 the combustion reaction and the consequent formation of hydrogen.

For example, it is known from US 2008/0063597 A1 to obtain a fuel composed of a mixture in the solid state of aluminum and gallium, the latter acting as a protective agent with respect to aluminum oxidation.

During the oxidation reaction, the gallium, being inert with respect to
5 water, undergoes no further transformations and remains as a waste product.

However, the use of this gallium- and aluminum-based fuel is not free from drawbacks, which include the fact that it requires production in suitable laboratory facilities and subsequent storage of fuel units, increasing time requirements and supply costs.

10 It is further necessary to provide systems for recovery and evacuation from the reaction chamber of the gallium that is released as a consequence of the oxidation of the fuel with water, which increase the complexity of its structure and increase its production and maintenance costs.

As an alternative, it is also known to provide chambers for the
15 reaction of aluminum in water within which elements are provided for performing machining on articles based on aluminum or alloys thereof, which are fed into the chamber at such machining region, in order to eliminate the film of protective oxide that coats these articles and make pure aluminum atoms available for reaction with water.

20 In particular, a plant for the production of gaseous hydrogen is known from JP2001031401 which uses a vessel for containing water, which is connected to a duct for the extraction of the generated hydrogen, inside which a cutting tool is accommodated which is immersed in water and is designed to machine a fuel based on aluminum or alloys thereof, which is
25 fed toward such tool. The rotary actuation of the cutting tool is obtained by means of a motor drive that is external to the vessel.

Moreover, US 2004/0208820 A1 discloses a method for generating hydrogen which entails providing a friction action and simultaneous mechanical fracture of a metallic material based on aluminum immersed in
30 water, so as to make available atoms of pure aluminum to trigger the

reaction with water. In particular, a plant is disclosed which is constituted by a reaction chamber provided with means for supplying water and with a duct for recovery of the gaseous hydrogen, which accommodates a grinding wheel immersed in water, toward which metallic material containing
5 aluminum in the solid state is fed. The rotary motion of the grinding wheel is actuated by an external electric motor.

However, even these plants are not free from drawbacks, including in particular the fact that they are designed exclusively to obtain gaseous hydrogen to be stored or fed toward suitable users and do not allow to
10 utilize the other energy sources made available as a consequence of the oxidation reaction.

Further, these plants require external supply sources both for the power or the fuel needed for the operation of the motor for the rotary actuation of the corresponding tools and for the process water required to
15 maintain the reaction.

Moreover, such plants make it difficult to adjust the quantity of hydrogen that is produced and, with particular reference to the plant disclosed by JP2001031401, have discontinuous operation, since the reaction chamber must be resupplied with water periodically.

20 **Disclosure of the Invention**

The aim of the present invention is to eliminate the above-mentioned drawbacks of the background art, by devising a metal-fueled cogeneration plant that allows to utilize not only the chemical potential energy of the hydrogen obtained from the oxidation of a metallic fuel in water but also the
25 heat generated by the water splitting reaction to generate heat energy, mechanical energy and/or electric power.

Within this aim, an object of the present invention is to provide an autonomous plant with continuous-cycle operation that constitutes a substantially closed system capable of sustaining itself once steady-state
30 conditions have been reached.

Another object of the present invention is to provide suitable treatments that allow to recycle the byproducts obtained in the reaction chamber and in particular the metallic oxides.

Another object of the present invention is to propose a compact plant
5 that can be applied easily in various fields, for example for the propulsion of land, naval or aerospace vehicles, in stationary power plants, and for cogeneration for civil and/or industrial use.

A further object of the present invention is to not release substances that pollute the environment and to have a limited environmental impact.

10 Another object of the present invention is to provide a plant which is simple, relatively easy to provide in practice, safe in use, effective in operation, and of relatively low cost.

This aim and these and other objects which will become better apparent hereinafter are achieved by the present metal-fueled cogeneration
15 plant, which comprises at least one reaction chamber, means for introducing at least one water-based liquid oxidizer, and means for supplying at least one metal-based fuel into said chamber, the oxidizer and the fuel being adapted to give rise to an exothermic oxidation reaction to obtain gaseous hydrogen and at least one metallic oxide, characterized in that said
20 introduction means are adapted to introduce in said chamber a quantity of oxidizer that is substantially greater than the stoichiometric quantity to form steam and comprises at least one fluid-based motive power unit that is fed in input by at least said steam for the rotary actuation of a driving shaft, separation and recovery means for said steam being interposed between the
25 chamber and the inlet to said motive power unit, and means for evacuation of said hydrogen being further provided.

Brief Description of the drawings

Further characteristics and advantages of the present invention will become better apparent from the following detailed description of a
30 preferred but not exclusive embodiment of a metal-fueled cogeneration

plant, illustrated by way of non-limiting example in the accompanying drawings, wherein:

Figure 1 is a schematic longitudinal sectional view of a cogeneration plant according to the invention;

5 Figure 2 is a block diagram that represents the architecture and the functional connections of the cogeneration plant according to the invention;

Figure 3 is a block diagram that represents the management and control unit of the cogeneration plant according to the invention.

Ways of carrying out the Invention

10 With reference to the figures, the reference numeral 1 generally designates a metal-fueled cogeneration plant.

The plant 1 comprises at least one reaction chamber 2, which is hermetic and suitably thermally insulated, means 3 for introducing at least one water-based liquid oxidizer into the chamber 2, and means 4 for
15 supplying at least one metal-based fuel into said chamber.

The oxidizer and the fuel are adapted to generate between them an exothermic oxidation reaction to obtain gaseous hydrogen and at least one metallic oxide in the solid and/or liquid state.

Advantageously, the introduction means 3 and the supply means 4
20 work continuously, supplying the chamber 2 in order to stably maintain said reaction.

The fuel is preferably fed in the solid state, but it might also be introduced in the chamber 2 also or exclusively in the liquid state.

The fuel further comprises at least one metal selected from the group
25 that comprises aluminum, magnesium, associated compounds and/or alloys. Preferably, the fuel is constituted by aluminum, compounds and/or alloys thereof.

The oxidizer is substantially constituted by water, optionally with the addition of protective, accelerating and/or catalytic substances of a known
30 type.

The reaction between water and aluminum therefore gives rise to the formation of gaseous hydrogen and alumina in the solid and/or liquid state.

Advantageously, the introduction means 3 are adapted to introduce a quantity of water that is substantially greater than the stoichiometric one to
5 maintain the oxidation reaction; the excess water, due to the heat generated by this reaction, is converted at least partially into steam.

The plant 1 therefore has at least one fluid-based motive power unit 5, which is fed in input by at least the steam to turn a driving shaft 6, between the chamber 2 and the inlet to the motive power unit 5 there being means 7
10 for separating and recovering at least the steam.

Preferably, as shown in Figure 1, the motive power unit 5 is fed in input both by the steam and by the hydrogen that are obtained in the chamber 2 and are removed from said chamber by way of the separation and recovery means 7.

15 The plant 1 is further provided with means 8 (shown schematically in Figure 2) for evacuating the hydrogen obtained, which are associated with the separation and recovery means 7, if the motive power unit 5 is supplied exclusively by the steam, or arranged downstream of the discharge of the motive power unit 5, when said machine is supplied by both fluids. The
20 evacuation means 8 can provide for the storage or conveyance of the hydrogen toward a user according to known technologies.

The motive power unit 5 is constituted by a turbine, the impeller 5a of which is jointly associated for rotation with the driving shaft 6. In an alternative embodiment, the motive power unit 5 can be constituted by an
25 external-combustion prime mover, such as for example a Stirling engine.

The chamber 2 lies substantially along a longitudinal axis A, so as to form a first end 2a and a second end 2b, which are mutually opposite and are associated with a fluid connection with the introduction means 3 and the separation and recovery means 7 respectively.

30 The supply means 4 comprise at least one tool 9, which is

accommodated in the chamber 2 so as to form a work area that is immersed in water and is associated with the driving shaft 6 for actuation with a cutting motion. In Figure 1, the tool 9 is of the type of a face mill and is keyed directly onto the driving shaft 6 at a first end that protrudes inside the chamber 2, the cutting motion being rotary. However, it is possible to provide for the use of a differently shaped tool, such as for example a grinding wheel. The supply means 4 further have pusher means 10 for introducing at least one article M made of fuel into the chamber 2 at said work area. The pusher means 10 preferably are adapted to supply the chamber 2 continuously. The mechanical action applied by the tool 9 to the article M is such as to obtain the formation of fragments of fuel of suitable size (for example having a diameter comprised between 10 and 100 micrometers), the exposed surfaces of which bear metallic particles that are reactive in the presence of water.

In particular, if aluminum-based fuel is used, the machining performed by the tool 9 allows to remove the film of alumina that coats the article M externally, which previously had remained in contact with air, and to make available particles of pure metal for reaction with water.

Advantageously, the article M can have an elongated shape and can be constituted by ordinary commercial bars, which are widely available commercially, the tool 9 being adapted to perform its end machining.

The tool 9 is arranged proximate to the first end 2a, at the longitudinal axis A, and the pusher means 9 are adapted to introduce the article M in the chamber 2 through an opening that is formed in the second end 2b parallel to said axis.

The plant 1 is provided with motor drive means 11 (schematically shown in Figure 2) for the initial actuation of the introduction means 3 and/or of the supply means 4. In particular, the motor drive means 11 are adapted to turn the driving shaft 6, producing the consequent triggering of the oxidation reaction in the chamber 2 until steady-state conditions are

reached in which said motor drive means are deactivated and rotation is imparted to the driving shaft 6 exclusively by the turbine 5. Moreover, the motor drive means 11 ensure the starting of the operation of any pumping devices provided within the means 3 for introducing the oxidizer and of any additional auxiliary users 12, such as the elements for activating the pusher means 10.

Figure 1 illustrates a flange 13 that is rigidly connected to a second end of the driving shaft 6, which lies opposite the first one and is arranged externally with respect to the chamber 2, for mating with the motor drive means 11, not shown in detail, which can be constituted by an electric motor of a conventional type.

The introduction means 3 comprise a manifold body 14, which is associated with a duct 15 for the intake of water, which is fed by a tank 16 by way of said pumping devices or directly from the water mains; the manifold body 14 has a fluid connection to the first end 2a and has a substantially annular shape around the longitudinal axis A, so as to form a central hole in which the driving shaft 6 is accommodated so that it passes through. The chamber 2 has, on the first end 2a, an opening, at the central hole of the manifold body 14, in which the driving shaft 6 is inserted so as to pass hermetically. The introduction means 3 further have a straightening partition 17, which is interposed between the manifold body 14 and the first end 2a, in order to give the water a motion in a direction that is substantially parallel to the longitudinal axis A along the chamber 2, toward the second end 2b. The straightening partition 17 is constituted by an annular plate provided with a plurality of cylindrical through holes distributed along its entire extension.

The separation and recovery means 7 comprise a stilling basin 18, which is associated with a fluid connection with the second end 2b by interposition of a slowing partition 19, which is constituted by an annular plate provided with a plurality of cylindrical through holes distributed along

its entire extension.

The basin 18 is provided, in an upper region, with at least one port 18a for the outflow of at least one between the hydrogen and the steam that have formed within the chamber 2 and, in a lower region, with at least one
5 second port 18b for the outflow of at least one between any excess water that is still in the liquid state and the metallic oxide that has formed, in particular alumina. In the plant shown in Figure 1, the entire gaseous phase, constituted by a mixture of steam and hydrogen directed toward the turbine
5 passes through the first port 18a, whereas the water and alumina exit from
10 the second port 18b. Downstream of the second port 18b, therefore, there is a first phase separation assembly 20, shown schematically in Figure 2, for the further separation of water and metal oxide, for example of the settling type. The plant 1 is further provided with first means 21 for transferring the water recovered by the first phase separation assembly 20 into the chamber
15 2 by way of the introduction means 3, and with a unit 22 for reducing the recovered metallic oxide and second means 23 for conveying the metal obtained from the reduction reaction in the chamber 2 directly or by way of the supply means 4.

In the case of use of fuel based on aluminum, alloys and/or
20 compounds thereof, the alumina reduction unit 22 can be of the electrolytic type, preferably with cells having inert anodes.

The basin 18 therefore has a substantially annular extension around the longitudinal axis A, so as to form a central hole at which the opening is formed of the second end 2b for the hermetic introduction of the article M.

25 Advantageously, first heat exchange means 24 are provided which operate at high pressure (generally higher than 30 bar), for at least partial recovery of the heat from at least the steam in output from the first port 18a and in input to the turbine.

If the turbine 5 is supplied in input by steam and hydrogen, the first
30 heat exchange means 24 process both fluids.

Figure 1 shows first heat exchange means 24 with separate fluids and isolated currents, which affect a duct 25 for connecting the first port 18a to the inlet of the turbine 5; the reference numerals 24a and 24b respectively designate the intake and discharge ports of a first working fluid that absorbs
5 heat from the hydrogen and from the steam.

It is further possible to provide means 26 for superheating the hydrogen and/or the steam upstream of the inlet to the turbine, shown schematically in Figure 2. The superheating means 26, if provided, are suitably connected upstream of the inlet to the first heat exchange means 24.
10 The superheating means 26 can be constituted for example by a portion of coiled duct arranged in the chamber 2 proximate to the work area of the tool 9 and to the region where the exothermic oxidation reaction is triggered and developed, which is crossed by the hydrogen and/or steam in output from the separation and recovery means 7.

15 The plant 1 further has second heat exchange means 27, which operate at low pressure (generally lower than five bars), associated with the outlet of the motive power unit 5 for the at least partial recovery of the heat from at least the steam and the corresponding condensation.

If the turbine 5 is fed in input by steam and hydrogen, the second heat
20 exchange means 27 process both fluids.

In Figure 1, the second heat exchange means 27, with separated fluids and isolated currents, are connected to the outlet of the turbine 5 by means of a duct 28 and are supplied both with the hydrogen and with the steam; the reference numerals 27a and 27b designate respectively the inlet and the
25 outlet of a second working fluid that absorbs heat from the hydrogen and from the steam.

There is, therefore, a second phase separation unit 29, which is associated so as to cooperate with the second heat exchange means 27 to separate the hydrogen from the water obtained from the condensation of the
30 steam. In the figures, the reference numerals 29a and 29b designate the

outlets respectively of hydrogen and condensation water.

The evacuation means 8 are associated with the discharge outlet 29a in order to store the hydrogen or send it to a user.

Finally, third means 30 for conveying the condensation water to the
5 chamber 2 by way of the introduction means 3 are provided.

With particular reference to Figures 2 and 3, of which the symbols used are referenced in brackets, it is noted that advantageously there are means, constituted by conventional sensors and/or transducers, for detecting the physical quantities which allow, according to formulas that are known to
10 the person skilled in the art, to calculate at least one among the values of thermal power (P_{HEAT}) transferred by the first and/or second heat exchange means 24 and/or 27, to the respective working fluids, mechanical power (P_M) made available by the motive power unit 5, and chemical potential energy (P_{H_2}) that corresponds to the produced quantity of hydrogen.

15 In greater detail, it is possible to provide means for detecting the values of:

- flow-rate, pressure and temperature of the oxidizer fed by the introduction means 3,
- pressure and temperature in the chamber 2 at the region where the
20 exothermic oxidation reaction is triggered and developed,
- pressure and temperature of the steam and/or hydrogen in input to the first heat exchange means 24,
- pressure and temperature of the steam and/or hydrogen in output from the first heat exchange means 24 or in input to the motive power unit
25 5,
- pressure and temperature of the steam and/or hydrogen in output from the motive power unit 5,
- flow-rate, pressure and temperature of the hydrogen in output from the first discharge port 29a and
- 30 – flow-rate, pressure and temperature of the condensation water in

output from the second discharge port 29b.

It is further possible to provide means for detecting the values of:

- the feed rate of the article M transmitted by the pusher means 10,
- the rotation rate and torque of the driving shaft 6,
- 5 – flow-rate, pressure and temperature of the first working fluid in input to the first heat exchange means 24,
- pressure and temperature of the first working fluid in output from the first heat exchange means 24,
- flow-rate, pressure and temperature of the second working fluid in
- 10 input to the second heat exchange means 27, and
- pressure and temperature of the second working fluid in output from the second heat exchange means 27.

The plant 1 is further provided with a management and control unit 31, which is shown schematically in Figure 3 and is adapted to receive the

15 corresponding signals of the physical values, process them in order to calculate at least one of the above cited values of thermal power (P_{HEAT}), mechanical power (P_M) and chemical potential energy (P_{H2}) yielded by the plant 1 and to compare the detected values with corresponding set values of heat power ($P_{HEAT}^{Requested}$), mechanical power ($P_M^{Requested}$) and/or chemical

20 potential energy ($P_{H2}^{Requested}$) in order to determine any positive or negative variations (ΔP_{HEAT} , ΔP_M , ΔP_{H2}) and accordingly manage the actuation of the introduction means 3 and/or of the feed means 4 so as to obtain detected values that are substantially equal to the set values.

In particular, if a variation of the detected value of thermal power

25 (ΔP_{HEAT}) with respect to the set value for a given flow-rate of water (\dot{m}_{H2O}) in input to the chamber 2 has been detected, the management and control unit 31 acts on the introduction means 3, setting a correlated positive or negative variation ($\Delta \dot{m}_{H2O}$) of the water flow-rate in input.

Moreover, in case of a variation of the detected value of mechanical

power (ΔP_M) or chemical potential energy (ΔP_{H2}) with respect to the corresponding set value, for a given flow-rate of aluminum (\dot{m}_{Al}) introduced in the chamber 2, the management and control unit 31 acts on the supply means 4, forcing a correlated positive or negative variation ($\Delta \dot{m}_{Al}$) of the flow-rate of aluminum in input.

In particular, the value of the mechanical power (P_M) made available by the motive power unit 5 can be obtained by processing the pressure and temperature values of the flow-rate of gaseous mix (\dot{m}_{mix}) in input to said motive power unit to calculate the corresponding enthalpy content (h_{mix}), from which the management and control unit 31 is capable of processing the datum related to the power that can be obtained from the motive power unit 5. At the same time, the management and control unit 31 is able to detect the mechanical power value required by the plant 1 from the values detected instantaneously of the torque and of the rotation rate at the driving shaft 6. When the mechanical power made available by the motive power unit 5 is sufficient to ensure that the driving shaft 6 continues to rotate at the desired speed and to cover the demand of the introduction means 3 and of any auxiliary users 12, the management and control unit 31 deactivates the motor drive means 11 and the plant 1 maintains itself autonomously. Any excess in the resulting mechanical power can be converted into electric power.

The management and control unit 31, not shown in detail, is of the type of a conventional electronic device, preferably of the programmable type, optionally provided with means for interfacing with the user to set the required values of thermal power ($P_{HEAT}^{Requested}$), mechanical power ($P_M^{Requested}$) and/or chemical potential energy ($P_{H2}^{Requested}$).

The operation of the present invention is as follows.

By way of the introduction means 3 and the supply means 4, water or other water-based oxidizer and aluminum, compounds and/or alloys thereof or another metal-based fuel are introduced continuously respectively in the

chamber 2, to trigger the oxidation reaction that leads to the generation of gaseous hydrogen and alumina or other metallic oxide.

Advantageously, the water is introduced continuously in the chamber 2 in a quantity that is greater than the stoichiometric quantity in order to
5 maintain the oxidation reaction, so that the excess water is converted continuously at least partially into steam thanks to the heat generated by the oxidation reaction.

The steam and optionally also the hydrogen contained in the chamber 2, after suitable separation from the other substances contained in the
10 chamber, are introduced in the turbine 5 or another fluid-based motive power unit in order to obtain mechanical power, which can optionally be converted into electric power. Before entering the turbine 5, the gaseous mix is preferably treated in superheating means 26, if provided, and in first heat exchange means 24 for heat recovery.

15 Any excess water and the alumina in output from the chamber 2 are treated in a first phase separation assembly 20, from which the water in output is sent in the chamber 2 and the alumina is reduced electrolytically so as to obtain again metallic aluminum to be introduced in the chamber 2.

In output from the turbine 5, the gaseous mix is treated in second heat
20 exchange means 27 for the further recovery of heat and then in a second phase separation unit 29 for separating condensation water, which can be introduced again into the chamber 2, and the hydrogen intended for corresponding users or for storage.

The plant according to the invention therefore allows to obtain
25 mechanical/electrical power, thermal power and chemical potential energy.

The method for cogeneration from metal fuel that is proposed in fact provides for the steps of:

- supplying at least one water-based liquid oxidizer,
 - supplying at least one metal-based fuel that is reactive by oxidation
- 30 to said oxidizer to form hydrogen and at least one metallic oxide, the

oxidizer being supplied in excess with respect to the stoichiometric quantity required according to said oxidation reaction,

- mixing the fuel and the oxidizer to obtain the reaction and the simultaneous generation of steam from the excess quantity of the oxidizer,
 - 5 – processing at least one between the hydrogen and the steam in a fluid-based motive power unit for the rotary actuation of at least one driving shaft,
 - recovering the hydrogen in output from the working machine,
- such steps constituting a continuous process.

- 10 Such method can further provide for the step of recovering heat from the steam and/or hydrogen upstream or downstream of passage within the motive power unit.

In practice it has been found that the described invention achieves the proposed aim and objects and in particular the fact is stressed that the plant
15 according to the invention and the corresponding cogeneration method allow to obtain, by utilizing a widely available metallic fuel, which is relatively cheap and nonpolluting, in addition to the chemical potential energy made available by the hydrogen obtained, also mechanical/electric and thermal power.

- 20 Further, the plant according to the invention allows to use at least part of the generated mechanical power to sustain its own operation, being autonomous in steady-state conditions with respect to external energy sources, which would increase its operating costs.

Moreover, the plant according to the invention provides for recycling
25 of the reaction byproducts, reducing operating costs.

Finally, the proposed plant is compact and flexible in application.

The invention thus conceived is susceptible of numerous modifications and variations, all of which are within the scope of the appended claims.

- 30 All the details may further be replaced with other technically

equivalent elements.

In practice, the materials used, as well as the contingent shapes and dimensions, may be any according to requirements without thereby abandoning the scope of the protection of the appended claims.

- 5 The disclosures in Italian Patent Application No. MO2008A000249 from which this application claims priority are incorporated herein by reference.

Where technical features mentioned in any claim are followed by reference signs, those reference signs have been included for the sole
10 purpose of increasing the intelligibility of the claims and accordingly, such reference signs do not have any limiting effect on the interpretation of each element identified by way of example by such reference signs.

CLAIMS

1. A metal-fueled cogeneration plant (1), comprising at least one reaction chamber (2), means (3) for introducing at least one water-based liquid oxidizer, and means (4) for supplying at least one metal-based fuel
5 into said chamber (2), the oxidizer and the fuel being adapted to give rise to an exothermic oxidation reaction to obtain gaseous hydrogen and at least one metallic oxide, characterized in that said introduction means (3) are adapted to introduce in said chamber (2) a quantity of oxidizer that is substantially greater than the stoichiometric quantity to form steam and
10 comprises at least one fluid-based motive power unit (5) that is fed in input by at least said steam for the rotary actuation of a driving shaft (6), separation and recovery means (7) for at least said steam being interposed between the chamber (2) and the inlet to said motive power unit (5), and means (8) for evacuation of said hydrogen being further provided.

15 2. The plant (1) according to claim 1, characterized in that said supply means (4) comprise at least one tool (9), which is accommodated within said chamber (2) so as to form a work area that is immersed in said oxidizer and is associated with said driving shaft (6) for actuation with a cutting motion and pusher means (10) for introducing at least one article (M) made of said
20 fuel into said chamber (2) at said work area, the mechanical action of the tool (9) on the article (M) being adapted to obtain the formation of fragments of said fuel whose exposed surfaces bear metallic particles that are reactive to the oxidizer.

3. The plant (1) according to one or more of the preceding claims,
25 characterized in that it comprises motor drive means (11) for the initial actuation of said introduction means (3) and/or of said supply means (4), in the steady state the actuation of the introduction means (3) and/or of the supply means (4) being sustained by the mechanical power provided by the motive power unit (5).

30 4. The plant (1) according to one or more of the preceding claims,

characterized in that said chamber (2) lies substantially along a longitudinal axis (A) so as to define a first end (2a) and a second end (2b) which are mutually opposite and are associated with a fluid connection respectively with said introduction means (3) and with said separation and recovery means (7).

5 The plant (1) according to one or more of the preceding claims, characterized in that said introduction means (3) comprise a manifold body (14), which is associated with a duct (15) for the inflow of said oxidizer, with a fluid connection to said first end (2a) and having a substantially
10 annular extension around said longitudinal axis (A), so as to define a central hole in which said driving shaft (6) is accommodated so as to pass through hermetically.

6. The plant (1) according to one or more of the preceding claims, characterized in that said introduction means (3) comprise a straightening
15 partition (17), which is interposed between said manifold body (14) and said first end (2a), so as to give said oxidizer a motion in a direction that is substantially parallel to said longitudinal axis (A) along said chamber (2).

7. The plant (1) according to one or more of the preceding claims, characterized in that said introduction means (3) and said supply means (4)
20 operate continuously.

8. The plant (1) according to one or more of the preceding claims, characterized in that said separation and recovery means (7) comprise a
stilling basin (18), which is associated with a fluid connection with said
second end (2b) by interposition of a slowing partition (19), the basin (18)
25 being provided with at least one port (18a) for the outflow of at least one between said hydrogen and said steam, which is associated with the inlet of said motive power unit (5), and with at least one second port (18b) for the outflow of at least one between said excess oxidizer and said metallic oxide.

9. The plant (1) according to one or more of the preceding claims,
30 characterized in that said tool (9) is arranged proximate to said first end (2a)

at said longitudinal axis (A) and in that said pusher means (10) are adapted to introduce said article (M) parallel to said longitudinal axis (A).

10 The plant (1) according to one or more of the preceding claims, characterized in that said basin (18) has a substantially annular extension around said longitudinal axis (A) so as to form a central hole at which said chamber (2) is provided with an opening for the hermetic insertion of said article (M).

11. The plant (1) according to one or more of the preceding claims, characterized in that it comprises first heat exchange means (24) for the at least partial recovery of heat from at least said steam in output from said chamber (2).

12. The plant (1) according to one or more of the preceding claims, characterized in that it comprises means (26) for superheating at least said steam which are arranged upstream of the inlet into said motive power unit (5).

13. The plant (1) according to one or more of the preceding claims, characterized in that it comprises second heat exchange means (27) which are associated with the outlet of said motive power unit (5) for the at least partial recovery of heat from at least said steam.

20 14. The plant (1) according to one or more of the preceding claims, characterized in that it comprises a first phase separation assembly (20), which is associated with said second discharge port (18b) for the separation of said excess oxidizer and of said metallic oxide, first means (21) for conveying the oxidizer to the chamber (2), a unit (22) for reducing the metallic oxide and second means (23) for conveying the metal obtained from the reduction reaction to the chamber (2) being provided.

15. The plant (1) according to one or more of the preceding claims, characterized in that said motive power unit (5) is supplied in input by said steam and by said hydrogen, the separation and recovery means (7) being adapted to allow the removal from said chamber (2) of the steam and of the

hydrogen and the evacuation means (8) being associated with the outlet of the motive power unit (5).

16. The plant (1) according to claim 14, characterized in that it comprises a second phase separation unit (29) which is associated so as to
5 cooperate with said second heat exchange means (27) to separate said hydrogen from the water obtained from the condensation of said steam, the evacuation means (7) being associated with the output of said second separation assembly (29) and third means (30) being provided for returning the condensation water to the chamber (2).

10 17. The plant (1) according to one or more of the preceding claims, characterized in that said motive power unit (5) is constituted by a turbine, the impeller (5a) of which is jointly associated for rotation with said driving shaft (6).

18. The plant (1) according to one or more of claims 1 to 16,
15 characterized in that said motive power unit (5) is constituted by an external-combustion prime mover.

19. The plant (1) according to one or more of the preceding claims, characterized in that said fuel comprises at least one metal selected from the group that comprises aluminum, magnesium, corresponding compounds
20 and/or alloys.

20. The plant (1) according to claim 19, characterized in that said fuel is constituted substantially by aluminum, compounds and/or alloys thereof.

21. The plant (1) according to one or more of the preceding claims, characterized in that said article (M) has a substantially elongated shape, the
25 tool (9) being adapted to work its end.

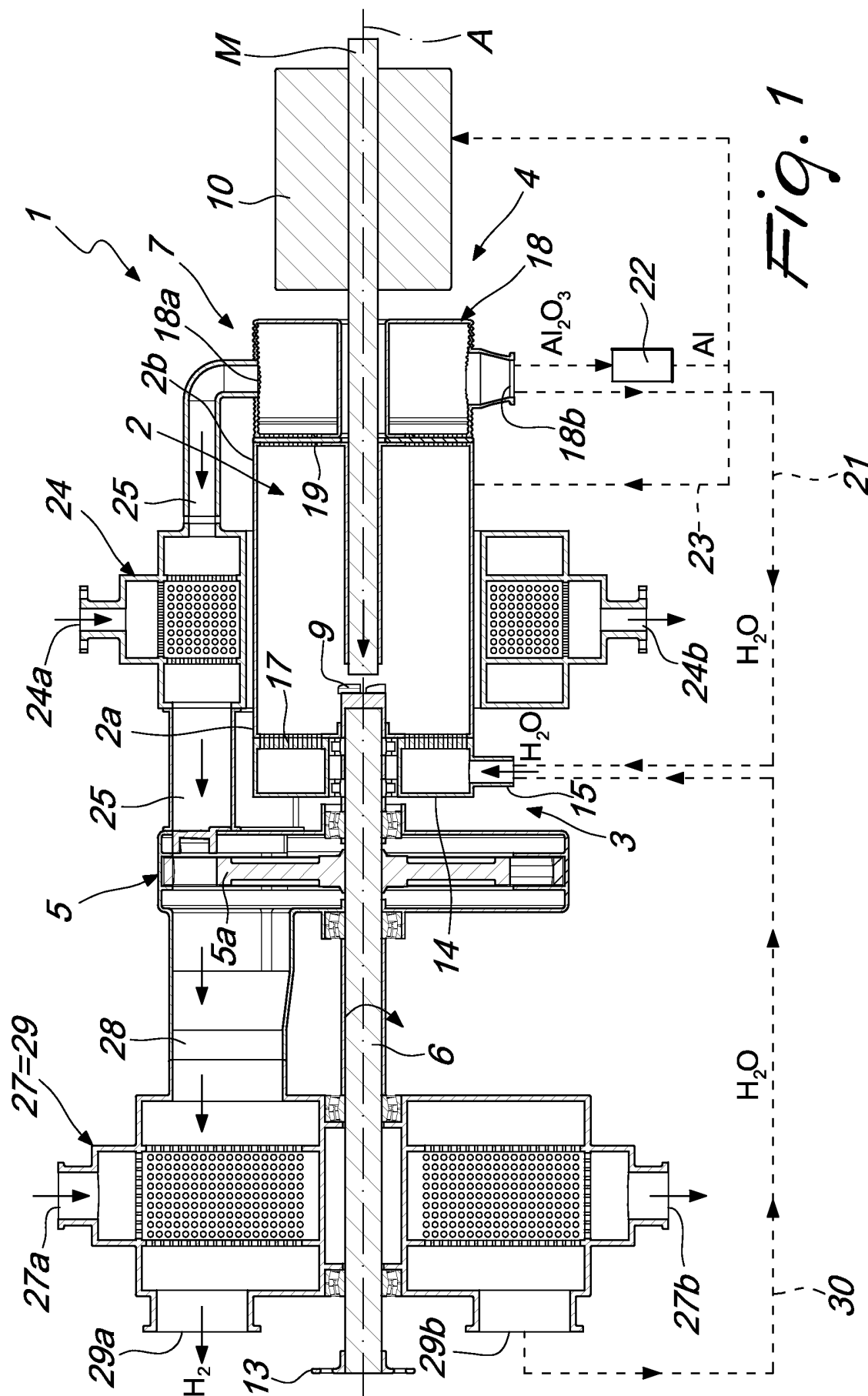
22. The plant (1) according to one or more of the preceding claims, characterized in that it comprises a management and control unit (31), which is adapted to process at least one among the values of thermal power (P_{HEAT}), mechanical power (P_{M}) and chemical potential energy (P_{H_2}) obtained
30 from the values of characteristic physical quantities measured by detection

means, to compare said at least one detected value with at least one corresponding set value of thermal power ($P_{HEAT}^{Requested}$), mechanical power ($P_M^{Requested}$) or chemical potential energy ($P_{H2}^{Requested}$) and to operate said introduction means (3) and/or said supply means (4) so as to obtain a
 5 detected value that is substantially equal to the corresponding set value.

23. A method for cogeneration from metallic fuel, which comprises the steps of:

- providing at least one water-based liquid oxidizer,
- supplying at least one metal-based fuel that is reactive by oxidation
 10 with said oxidizer in order to form hydrogen and at least one metallic oxide, the oxidizer being supplied in excess with respect to the stoichiometric quantity required according to said oxidation reaction,
- mixing said fuel and said oxidizer to obtain said reaction and the simultaneous generation of steam from the excess quantity of said oxidizer,
- 15 – treating at least one between said hydrogen and said steam in a fluid-based motive power unit for the rotary actuation of at least one driving shaft,
- recovering said hydrogen in output from said motive power unit (5), said steps constituting a continuous process.

20 24. The method according to claim 23, characterized in that it comprises the step of recovering heat from said at least one between said hydrogen and said steam upstream and/or downstream of the passage within said motive power unit (5).



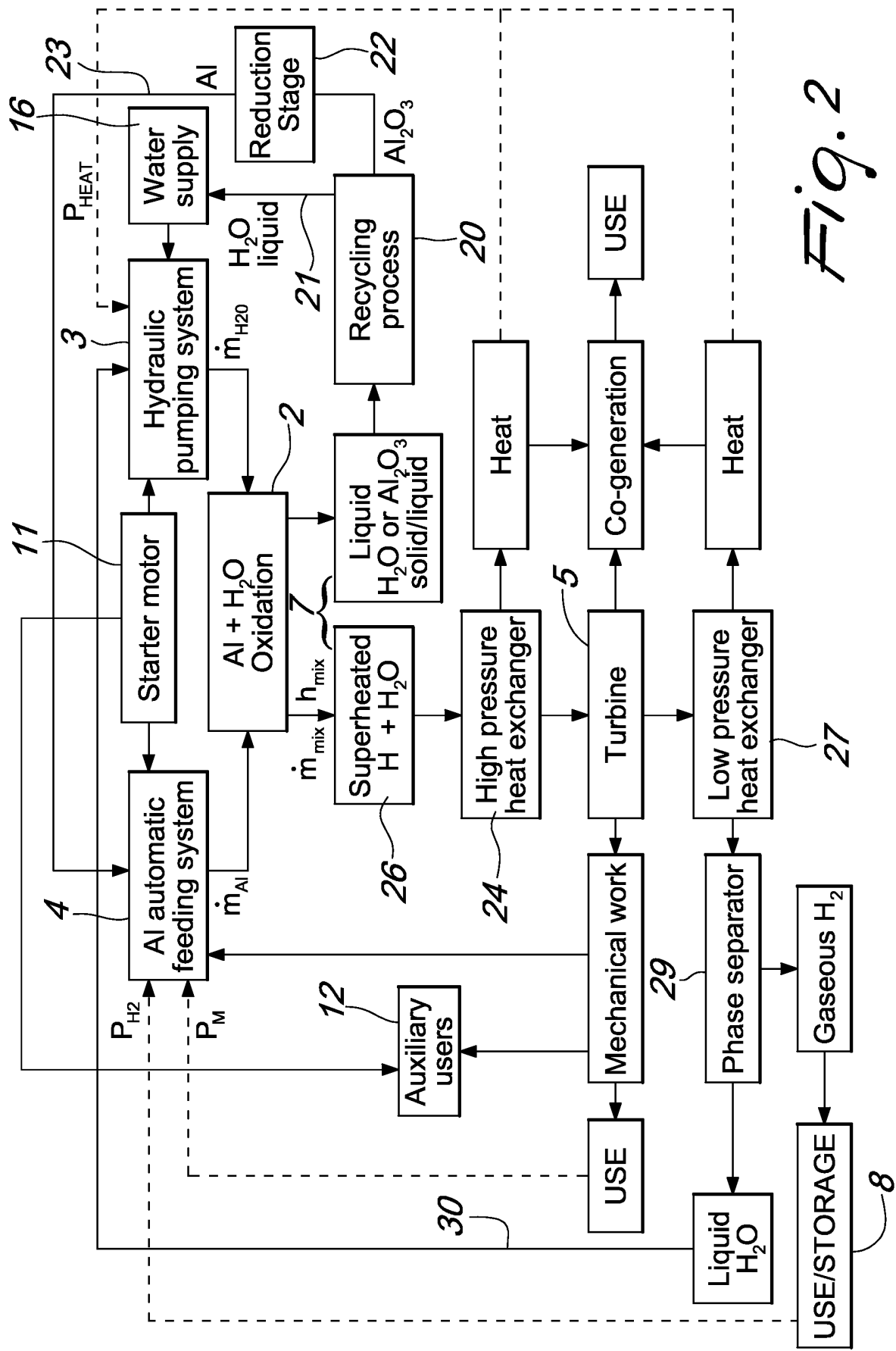
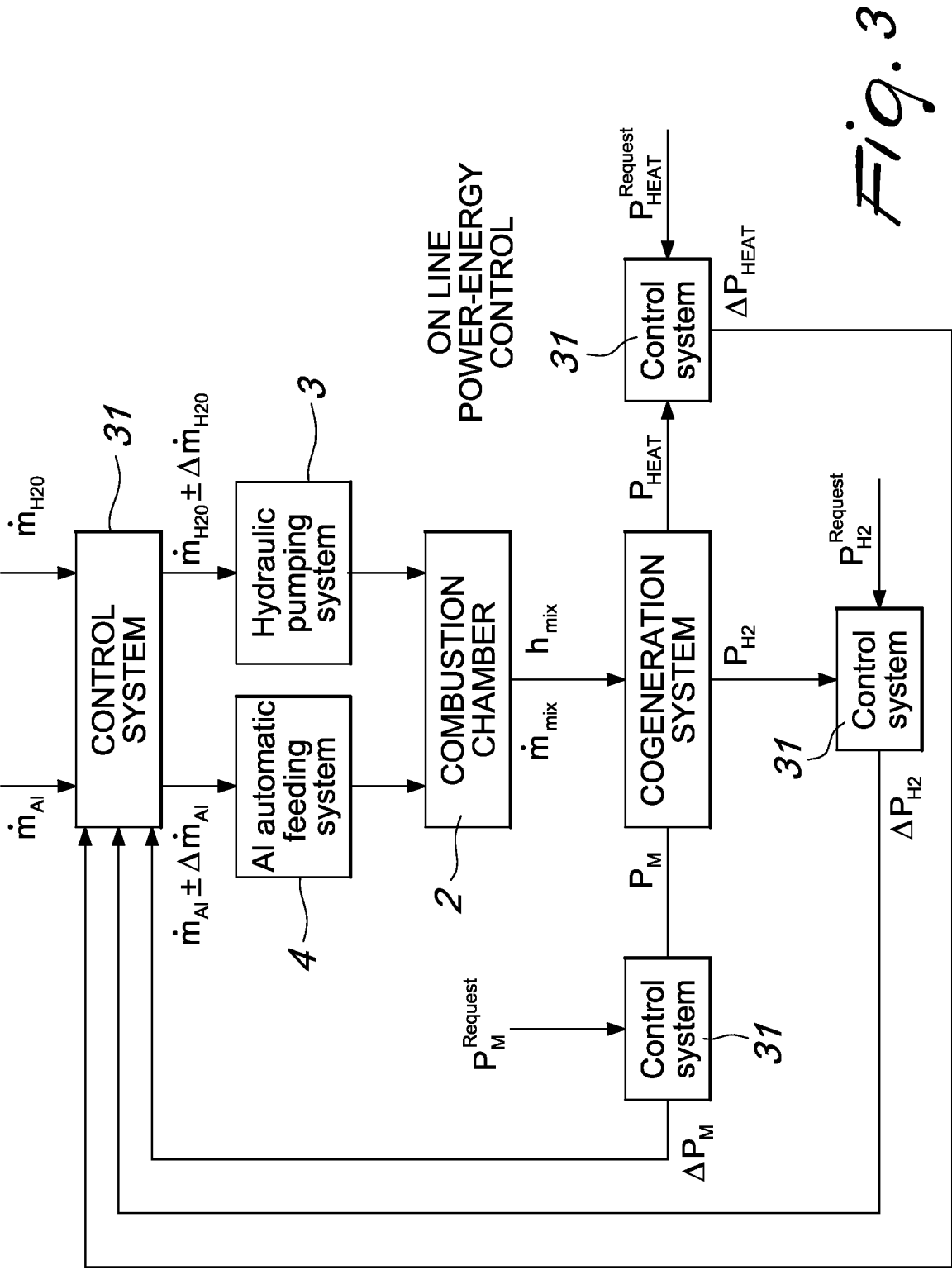


Fig. 2



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/062334

A. CLASSIFICATION OF SUBJECT MATTER INV. C01B3/08		
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) C01B F24J F25B		
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 practical, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 143 047 A (LEE WOODROW W [US]) 1 September 1992 (1992-09-01) column 1, line 63 - column 2, line 32 column 2, line 51 - column 3, line 12 -----	1,23
A	US 6 506 360 B1 (ANDERSEN ERLING REIDAR [NO] ET AL) 14 January 2003 (2003-01-14) column 6, line 4 - line 20 column 7, line 26 - line 48 -----	1,23
A	EP 1 867 603 A (HITACHI MAXELL [JP]) 19 December 2007 (2007-12-19) paragraphs [0062], [0063] -----	1,23
<div style="display: flex; justify-content: space-between;"> <input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex. </div>		
<div style="display: flex;"> <div style="flex: 1;"> <p>* Special categories of cited documents :</p> <p>*A* document defining the general state of the art which is not considered to be of particular relevance</p> <p>*E* earlier document but published on or after the international filing date</p> <p>*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>*O* document referring to an oral disclosure, use, exhibition or other means</p> <p>*P* document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="flex: 1;"> <p>*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</p> <p>*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</p> <p>*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.</p> <p>*&* document member of the same patent family</p> </div> </div>		
Date of the actual completion of the international search <div style="text-align: center; font-weight: bold;">30 November 2009</div>		Date of mailing of the international search report <div style="text-align: center; font-weight: bold;">08/12/2009</div>
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer <div style="text-align: center; font-weight: bold;">Pileri, Pierluigi</div>

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2009/062334

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5143047	A	01-09-1992	NONE	
US 6506360	B1	14-01-2003	NONE	
EP 1867603	A	19-12-2007	WO 2006103959 A1 KR 20070064645 A	05-10-2006 21-06-2007