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(54) **A UREA PRODUCTION PROCESS AND PRODUCTION PLANT USING CO2 PRODUCED BY OXY-COMBUSTION**

VERFAHREN ZUR HERSTELLUNG VON HARNSTOFF UND PRODUKTIONSANLAGE UNTER  
VERWENDUNG VON DURCH OXY-VERBRENNUNG ERZEUGTEM CO2

PROCÉDÉ DE PRODUCTION D'URÉE ET INSTALLATION DE PRODUCTION UTILISANT LE CO2  
PRODUIT PAR OXY-COMBUSTION

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## Description

### CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims priority from Italian Patent Application No. 102017000090748 filed on August 4, 2017.

### TECHNICAL FIELD

**[0002]** This invention relates to a urea production process and production plant using CO<sub>2</sub> produced by oxy-combustion of a carbon supply.

**[0003]** The requirements of environmental protection are increasingly felt and require inter alia a careful monitoring of CO<sub>2</sub> emissions.

**[0004]** Therefore, in various industrial sectors the adoption of solutions characterised by high energy efficiency and by the reduction in the emission of pollutants and of CO<sub>2</sub> is sought, for example through the recycling of the latter.

### BACKGROUND ART

**[0005]** In the industrial urea production complexes, that normally include an ammonia plant and a urea plant, the CO<sub>2</sub> required for urea synthesis is recovered in the ammonia plant via process gas cleaning with known technologies and is sent to the urea plant. The quantity of CO<sub>2</sub> recoverable from the ammonia plant is a function of the capacity of the plant itself (in terms of produced ammonia) and of the supply composition. Especially in cases of supply with a high methane content gas (so-called "light" fuels) the quantity of produced CO<sub>2</sub> can prove to be limiting, with respect to the available ammonia, for the capacity of the urea plant. In these cases, the solutions adopted to increase the quantity of available CO<sub>2</sub> are basically two:

1. enlargement of the ammonia plant's process gas production section (that is the section designated to produce hydrogen starting from fossil fuel);
2. the capture of CO<sub>2</sub> from the exhausts of the reforming oven and/or from other chimneys (gas turbines, auxiliary boilers, etc.) typically following washing with amine or with another solvent and subsequent regeneration. The separation occurs by physical-chemical absorption of CO<sub>2</sub>, that in order to be used has to be compressed at suitable pressures for the urea synthesis reaction.

**[0006]** However, these solutions may cause further problems themselves.

**[0007]** In particular, in the case of ammonia plants based on reforming or gasification, the enlargement of the ammonia plant's process gas production section in order to increase the production of CO<sub>2</sub> entails a corresponding increase of energy consumption; instead, in

case of CO<sub>2</sub> recovery from chimneys the costs to be borne for the installation of a new unit and the operating costs for the regeneration and the reintegration of the solvent have to be considered.

**[0008]** On the other hand, with ammonia plants that are based on reforming or gasification of hydrocarbons (for example in case H<sub>2</sub> and N<sub>2</sub> are available from other sources external to the plants) it is not possible to convert the produced ammonia in urea due to the lack of CO<sub>2</sub> that should be made available from other sources.

**[0009]** A known technology for the production of CO<sub>2</sub> is based on oxy-combustion processes.

**[0010]** Briefly, oxy-combustion is a kind of combustion in which a fuel is burnt using oxygen as primary oxidant instead of air.

**[0011]** In general, since air's nitrogen is not present, the concentration of CO<sub>2</sub> in the oxy-combustion's discharged exhausts increases. Indeed oxy-combustion mainly produces water vapour and concentrated carbon dioxide, simplifying the separation of CO<sub>2</sub> and/or its recycling. The discharged exhausts have a significantly lower nitrogen content compared with what can be obtained with the traditional combustion processes (and therefore also a definitely lower content of nitrogen oxides that are instead normally produced in the traditional air combustion processes and constitute particularly dangerous pollutants) and mostly contain CO<sub>2</sub> and water vapour. Therefore, by cooling the discharged gases in order to condense the water, CO<sub>2</sub> is recovered with minimal energy consumption. Moreover, the absence of nitrogen in the combustion process results in an improvement of the energy efficiency of the system since the heating of inert materials is avoided.

**[0012]** An example of the application of oxy-combustion for the recovery of CO<sub>2</sub> in industrial ammonia and urea production processes/plants is described in US2015/0183650.

**[0013]** In particular, US2015/0183650 describes the integration of an ammonia synthesis section with a standard oxy-combustion system. Such an ammonia synthesis section comprises an ammonia synthesis unit, where crude ammonia is produced starting from hydrogen and nitrogen; and a separation unit where the raw ammonia is condensed and separated from the unreacted nitrogen and hydrogen to produce a flow of purified ammonia. An oxy-combustion reactor, where the combustion of a fuel in the presence of oxygen coming from an air separation unit takes place, is used to generate hot water or steam, to be thermally integrated with the ammonia plant, in particular by thermal connection lines that connect the oxy-combustion reactor to the ammonia synthesis unit, and/or the air separation unit with the ammonia separation unit.

**[0014]** The integrated plant described in US2015/0183650 produces ammonia (using the hydrogen available from other sources external to the plant and nitrogen obtained from the air separation section) and CO<sub>2</sub> captured in the oxy-combustion process. In a specific application the conversion of the products them-

selves (ammonia and CO<sub>2</sub>) into urea is also foreseen, in a dedicated urea plant.

**[0015]** In the US2015/0183650 solution, the plant for the production of ammonia is necessary both for the purification of the exhausts exiting from the standard oxy-combustion section (with a high NO<sub>x</sub> and SO<sub>x</sub> content if the fed supply contains nitrogen and sulphur) and for the subsequent urea synthesis, if present.

**[0016]** The plants and processes of the kind described in US2015/0183650, like other essentially similar ones, may however prove to be not entirely satisfactory, at least for some applications.

**[0017]** For example, in the hypothesis described above of a urea production plant in which the CO<sub>2</sub> proves to be limiting with respect to the available ammonia, the US2015/0183650 solution is not applicable for the following reasons:

- additional ammonia synthesis and separation sections thermally integrated with the oxy-combustion unit are required. Therefore, it is not possible to produce only the CO<sub>2</sub> requested to close the material balance without producing ammonia at the same time;
- H<sub>2</sub> has to be made available from another unit of the plant.

**[0018]** Moreover, the generic oxy-combustion does not enable to feed multiple supplies of whatever nature and it can be subject to the typical problems of any burner linked to variations in the fuel flow.

#### DISCLOSURE OF INVENTION

**[0019]** One of the purposes of this invention is that of supplying a urea process and a urea production plant that enable to overcome the highlighted drawbacks of the prior art.

**[0020]** In particular, one of the purposes of the invention is that of improving the efficiency of the known urea production processes/plants and to increase their flexibility in terms of kind and flow rate of the supply.

**[0021]** Therefore, this invention relates to a urea process and to a urea production plant as essentially defined in the annexed claims 1 and, respectively, 13.

**[0022]** Additional preferred features of the invention are specified in the dependent claims.

**[0023]** According to the invention, a part or all the carbon dioxide required for the urea synthesis is produced in an oxy-combustion process of a carbon supply carried out with specific modes: specifically, the oxy-combustion process is a flameless oxy-combustion process, preferably pressurised.

**[0024]** In this way, the oxy-combustion process and the related oxy-combustion unit in which it is carried out are integrated in the urea process/production plant in a much more efficient and beneficial way compared with the prior art, in particular compared with the solution pro-

posed by US2015/0183650, allowing to manage the feeding of carbon supplies having a different physical state and a different composition and with variable flows inside the same combustor without having exhausts with a high content of NO<sub>x</sub> and SO<sub>x</sub> that require purification.

**[0025]** The oxy-combustion is carried out in a specific reactor, preferably pressurised, that can be integrated inside already existing or new urea plants.

**[0026]** The invention thereby gains the following main advantages:

- the capture of CO<sub>2</sub> is significantly simplified due to its high concentration in the exhausts and the low content of contaminants and inert materials;
- the wide flexibility of the carbon supply which can be fed enables the use of waste from adjacent plants, otherwise difficult to dispose of and/or to manage;
- a surplus of electric energy and/or steam can be exported and/or integrated inside the complex in which one is operating, increasing its efficiency;
- by carrying out pressurised flameless oxy-combustion, the pressurised CO<sub>2</sub> can be captured, reducing the compression costs for bringing it to the pressure required by the urea plant;
- by carrying out flameless and pressurised oxy-combustion one can considerably reduce the exhaust treatment section, in which, in particular, no washing with ammonia is necessary;
- it is possible to reduce (and in some particular cases, depending on the fed supply, even eliminate) the quantity of passivation air possibly required by the urea plant by exploiting the excess oxygen in the combustion exhausts;
- it is possible to associate a urea plant with the ammonia plant also when the ammonia is produced with technologies which are different from reforming or gasification of hydrocarbons, for example starting from pure H<sub>2</sub> and N<sub>2</sub>.

**[0027]** In short, the invention enables to increase the capacity of the existing urea production plants, assuring the quantity of required CO<sub>2</sub> with respect to the available ammonia.

**[0028]** Moreover, it is possible to use the CO<sub>2</sub> produced through the oxy-combustion process/plant in a new urea plant, irrespective of the urea production process and possibly having available ammonia from other sources.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0029]** Further characteristics and advantages of the present invention will become clear from the description of the following non-limiting embodiments thereof, with reference to the accompanying drawings, in which:

- Figure 1 is a block diagram showing in schematic and simplified form a urea production plant,

equipped with an integrated oxy-combustion unit, in accordance with the invention;

- Figure 2 is a schematic view of a variation of the Figure 1 plant, also comprising an ammonia unit for the production of ammonia.

#### BEST MODE FOR CARRYING OUT THE INVENTION

**[0030]** In Figure 1 a urea production plant as a whole is indicated with 1 comprising a urea unit 2 for producing urea by reaction of ammonia and carbon dioxide, and an oxy-combustion unit 3 in which carbon dioxide (CO<sub>2</sub>) is produced to be sent to the urea unit 2 for feeding the urea synthesis reaction from ammonia and carbon dioxide.

**[0031]** The urea unit 2 (that can also be an existing unit, "enhanced" with the integration of the oxy-combustion unit 3) is per se essentially known and therefore not described nor shown in detail for simplicity.

**[0032]** The urea unit 2, as also the urea production process carried out in it, can be of various kinds.

**[0033]** For example, but not necessarily, the urea unit 2 can be configured to carry out a traditional so-called "Snamprogetti™ Urea Technology" urea process, but it is understood that the invention is also applied to other urea production plants/processes.

**[0034]** In general, the urea unit 2 mainly comprises: a urea synthesis section, where the urea reaction synthesis from ammonia and carbon dioxide takes place; some recovery sections (for example a high pressure recovery section, a medium pressure recovery section and a low pressure recovery section), in which a urea solution produced in the synthesis section gradually concentrates with the removal from it of unreacted ammonia and carbon dioxide and water and recirculation of the recovered components; a vacuum concentration section connected to a section for the treatment of process condensates (essentially water); a finishing/solidification section, comprising for example a granulation unit or a prilling tower.

**[0035]** The urea unit 2 receives CO<sub>2</sub> (to be used as reagent in the urea reaction synthesis) produced in the oxy-combustion unit 3.

**[0036]** The oxy-combustion unit 3 is fed, by a fuel supply line 4, with a carbon supply (fuel) and, by an oxygen supply line 5, with an oxygen stream (oxidant).

**[0037]** The supply fed by the oxy-combustion unit 3 can be of any kind and physical state (for example low heating value gas, liquid or solid refinery residues, waste material, biomasses, coal, etc.). If necessary, for example in the case of coal-fired power, the supply can be pretreated, prior to being fed to the oxy-combustion unit 3, in a pretreatment unit 6 positioned along the fuel supply line 4.

**[0038]** The oxygen that feeds the oxy-combustion unit 3, is produced in an oxygen generation unit 7, connected to the oxy-combustion unit 3 by the oxygen supply line 5.

**[0039]** The oxygen generation unit 7 is for example an air separation unit, per se essentially known, configured to separate the air in nitrogen and oxygen.

**[0040]** The separation of the air can be carried out with any known technology, for example by fractional distillation or cryogenic fractionation, membrane separation, adsorption on suitable materials (molecular sieves, zeolites, etc.), in particular by so-called pressure swing absorption techniques (Pressure Swing Adsorption, PSA) or vacuum swing absorption (Vacuum Swing Adsorption, VSA) or with hybrid solutions (Vacuum Pressure Swing Adsorption, VPSA).

**[0041]** It is understood that the oxygen generation unit 7 can be of another kind, for example of the kind operating by electrolysis of aqueous solutions.

**[0042]** Advantageously, as shown in Figure 2, in the event that the urea production plant 1 includes or is adjacent to an ammonia unit 8 where ammonia is produced and the ammonia unit 8 is based on an autothermal reforming technology (AutoThermal Reforming, ATR) that makes use of a cryogenic air separation unit, the oxygen generation unit 7 is an air separation unit defined by said already existing cryogenic air separation unit, with a clear reduction of the investment and operating costs. The oxygen generation unit 7 (that is the air separation unit) is therefore connected, in addition to the oxy-combustion unit 3, also to the ammonia unit 8, by a nitrogen line 9 and an oxygen line 10 that feed nitrogen and oxygen to the ammonia unit 8.

**[0043]** The quantity and purity of the oxygen required by the oxy-combustion unit 3, are in any case such to make the air separation possible also with technologies alternative to cryogenic fractionation, more convenient in terms of investment, as the already mentioned techniques of adsorption or membrane separation that supply oxygen with 90-95%vol or lower content.

**[0044]** In general, the oxy-combustion unit 3 is fed by an oxygen stream containing at least about 80%vol, preferably at least 90%vol, of oxygen.

**[0045]** The oxy-combustion unit 3 is specifically a flameless oxy-combustion unit, in particular a flameless and pressurised oxy-combustion unit, configured so as to perform a flameless oxy-combustion, in particular a flameless and pressurised oxy-combustion, of the fuel in the presence of oxygen.

**[0046]** In the flameless oxy-combustion process (preferably pressurised) carried out in the oxy-combustion unit 3, specifically in a combustor (combustion chamber) of the oxy-combustion unit 3, the carbon supply (fuel) is burnt with the oxygen in such operating conditions that the combustion occurs without generating a flame.

**[0047]** According to the invention, the combustor of the oxy-combustion unit 3, is a flameless combustor, preferably pressurised and isothermic.

**[0048]** Preferably, the combustor's operating pressure ranges between 0 and 40 bar g.

**[0049]** Preferably, the combustion temperature ranges between about 800 and about 1800°C, preferably between about 1000 and about 1500°C.

**[0050]** As an example, the flameless oxy-combustion process (preferably pressurised) is carried out with the

modes and in a combustor of the kind described in one or more of the following documents: WO2009071230, WO2009071238, WO2009071239, WO2014016235, WO2014016237, WO2015097001.

**[0051]** The oxy-combustion process produces exhausts, containing in particular CO<sub>2</sub> and that exit from the oxy-combustion unit 3 by an exhaust line 11, and melted waste, that are solidified and inertised and then removed from the oxy-combustion unit 3 through a discharge line 12.

**[0052]** The oxy-combustion unit 3 is connected by the exhaust line 11 to an energy recovery unit 13.

**[0053]** The exhausts produced by the oxy-combustion process, indicatively at temperatures ranging between 1000 and 1500°C, are sent through the exhaust line 11 to the energy recovery unit 13 where the thermal energy is converted into steam and/or electric energy to support the energy consumption of plant 1.

**[0054]** The energy recovery unit 13 is therefore configured so as to recover heat from said exhausts produced in the oxy-combustion unit 3 and produce steam and/or electric energy.

**[0055]** For example, the energy recovery unit 13 comprises a boiler fed with water by a water line 14 and that produces steam, which is used as heating fluid to heat other process fluids in plant 1 and/or to generate electric energy by a turbine coupled with a generator.

**[0056]** In particular, steam and/or electric energy generated in the energy recovery unit 13 are used, for example, in a purification and compression unit 15 (described below), that feeds the urea unit 2 with CO<sub>2</sub>, or in the oxygen generation unit 7.

**[0057]** A possible excess of steam and/or electric energy is integrated with the existing network of plant 1 thereby improving the overall efficiency of the plant itself, or is exported (that is supplied to users that are external to plant 1).

**[0058]** The steam can be produced in the energy recovery unit 13 at any wanted pressure level (for example by extracting steam from different stages of the steam turbine) so that it may be easily integrated with the existing plant.

**[0059]** Thus, when the oxy-combustion unit 3 is inserted in a pre-existing urea production plant 1 with the resulting increase in urea production capacity, part of the steam and/or energy produced in the energy recovery unit 13 can be sent to the urea unit 2 to support the greater consumption indeed due to the increase in the production capacity.

**[0060]** Another way to generate electric energy could be for example through a supercritical CO<sub>2</sub> cycle instead of a traditional steam cycle.

**[0061]** Part of the exhausts exiting from the energy recovery unit 13 is recircled, by an exhaust recirculation line 16 fitted with a blower 17, to the oxy-combustion unit 3 and possibly to the energy recovery unit 13.

**[0062]** In particular, the exhaust recirculation line 16 inserts itself in the oxygen supply line 5 with a first arm

16a and is optionally connected, by a second branch 16b, to the energy recovery unit 13.

**[0063]** The remaining part of the exhausts exiting from the energy recovery unit 13 is treated in a CO<sub>2</sub> recovery section 20 configured so as to recover (separate) CO<sub>2</sub> from the exhausts with the CO<sub>2</sub> purity specification suitable for feeding the urea reaction synthesis carried out in the urea unit 2.

**[0064]** The energy recovery unit 13 is then connected by a portion 11a of the exhaust line 11 to the CO<sub>2</sub> recovery section 20.

**[0065]** For example, the CO<sub>2</sub> recovery section 20 comprises an exhaust treating unit 21, a condensation unit 22, and a purification and compression unit 15, connected to the energy recovery unit 13 and to each other, in series, by respective portions 11a, 11b, 11c of the exhaust line 11.

**[0066]** The exhausts treatment is essentially needed in order to remove from the exhausts pollutants possibly present in the carbon supply fed by the oxy-combustion unit such as sulphur, chlorine, etc.

**[0067]** The kind of exhausts treatment depends on the composition of the carbon supply fed by the oxy-combustion unit and therefore on the pollutants that are present.

**[0068]** For example, if a carbon supply high in sulphur is fed, the exhaust treating unit 21 must be configured to remove the sulphur up to the specification required by the final user and/or by the subsequent treatments; amongst the various possibilities, for example, a lime-based treatment can be carried out. If chlorine is present in the fed supply, a treatment based on caustic soda can be effected, etc.

**[0069]** Clearly, the exhaust treating unit 21 can be configured to perform various different treatments; nevertheless, the treatments are in any case simpler and require a lower energy consumption compared with those downstream both in traditional combustion and in generic oxy-combustion.

**[0070]** In one embodiment, an excess of oxygen is present in the exhausts produced by the oxy-combustion process. The excess of oxygen in the exhausts is usefully maintained in the CO<sub>2</sub> stream fed to the urea unit 2, since it enables to reduce the quantity of passivation air possibly mixed with CO<sub>2</sub> to allow the passivation of the metal surfaces in the urea unit 2, with a further improvement of plant 1's overall efficiency.

**[0071]** The exhausts treated in the exhaust treating unit 21 are then sent to the condensation unit 22, where they undergo condensation for the removal of the water which is present that is removed through a condensates recovery line 23; and then to the purification and compression unit 15, where the CO<sub>2</sub> is separated from the exhausts. The CO<sub>2</sub> stream separated from the exhausts is fed to the urea unit 2 by a CO<sub>2</sub> supply line 24, while the exhausts full of inert materials are discharged, for example to a chimney, by an exhaust discharge line 25.

**[0072]** In one embodiment, the gaseous stream com-

ing from the oxy-combustion unit 3 and from the energy recovery unit 13 via the portion 11a of the exhaust line 11 already has the purity specifications required by the urea unit 2; in this case, usefully, the recovery section 20 only comprises the condensation unit 22 (since the exhaust treating unit 21 is unnecessary) and a unit 15 reduced to only a compression unit (with no need for purification).

**[0073]** The exiting from the purification and compression unit 15 is sent to the urea unit 2 and introduced in the most suitable part of the urea unit 2, preferably already at the required pressure and possibly mixed with a stream already available at plant 1.

**[0074]** In one embodiment, the oxy-combustion unit 3 and the subsequent recovery section 20 supply all the carbon dioxide needed by the urea unit 2.

**[0075]** In this case, the stream exiting from the purification and compression unit 15 is fed directly by the synthesis section of the urea unit 2, at a pressure of about 140-200 bar and at a temperature of about 90-150°C.

**[0076]** In other embodiments, the stream coming from the purification and compression unit 15 is sent instead to the exit (discharge) of a compressor of the urea unit 2 (at a pressure of about 160 bar g or higher), at the entry (intake) of the same compressor (at a pressure of 0 and 2 bar g) or in one of the intermediate steps (at an intermediate pressure between 2 and 160 bar g).

## Claims

1. An urea production process comprising a step of synthesis of urea by reaction of ammonia and carbon dioxide, at least part of the carbon dioxide for the urea reaction synthesis being produced in an oxy-combustion process; **characterised in that** the oxy-combustion process is a flameless oxy-combustion process.
2. The process according to claim 1, wherein the oxy-combustion process is a flameless and pressurised oxy-combustion process.
3. The process according to claim 1 or 2, wherein the oxy-combustion process is carried out at a combustion temperature ranging between about 800 and about 1800°C, preferably between about 1000 and about 1500°C.
4. The process according to one of the preceding claims, wherein the oxy-combustion process is carried out at a pressure ranging between 0 and 40 bar g.
5. The process according to one of the preceding claims, wherein the oxy-combustion process is fed with oxygen produced in a step of oxygen generation, in particular in an air separation step.

6. The process according to one of the preceding claims, wherein at least part of the ammonia for the urea synthesis reaction is produced in a step of synthesis of ammonia by direct reaction of hydrogen and nitrogen, the nitrogen being produced in an air separation step together with oxygen; and wherein a part of the oxygen produced in air separation step feeds the oxy-combustion process.
7. The process according to one of the preceding claims, wherein the oxy-combustion process is fed with an oxygen stream containing at least about 80%vol, preferably at least 90%vol, of oxygen.
8. The process according to one of the preceding claims, comprising an energy recovery step, in which thermal energy is recovered from exhausts produced in the oxy-combustion process for producing steam and/or electric energy.
9. The process according to claim 8, comprising a step of recirculating a part of the exhausts to the oxy-combustion process and/or to the energy recovery step.
10. The process according to one of the preceding claims, comprising a step of recovering, i.e. separating, a stream from at least a part of exhausts containing and produced in the oxy-combustion process.
11. The process according to claim 10, wherein the step of recovering comprises the steps of: treating the exhausts for removing pollutants from the exhausts, condensing the exhausts by removing condensate water and obtaining a stream, and purifying and compressing the stream.
12. The process according to one of the preceding claims, wherein in the exhausts produced by the oxy-combustion process there is an excess of oxygen which is maintained in the stream fed to the urea synthesis reaction, to act as a passivation agent.
13. A urea production plant (1), comprising a urea unit (2) for producing urea by reaction of ammonia and carbon dioxide, and an oxy-combustion unit (3) in which carbon dioxide is produced to be sent to the urea unit (2) for feeding the urea synthesis reaction from ammonia and carbon dioxide; **characterised in that** the oxy-combustion unit (3) is a flameless oxy-combustion unit comprising a flameless combustor configured so as to perform a flameless oxy-combustion process of a carbon supply.
14. The plant according to claim 13, wherein the oxy-combustion unit (3) is a flameless and pressurised oxy-combustion unit and said combustor is pressu-

rised.

15. The plant according to claim 13 or 14, wherein the combustor operates at a combustion temperature ranging between about 800 and about 1800°C, preferably between about 1000 and about 1500°C. 5
16. The plant according to one of claims 13 to 15, wherein the combustor operates at a pressure ranging between 0 and 40 bar g. 10
17. The plant according to one of claims 13 to 16, wherein the oxy-combustion unit (3) is connected to an oxygen generation unit (7), in particular an air separation unit, connected to the oxy-combustion unit (3) by an oxygen supply line (5) for feeding oxygen to the oxy-combustion unit (3). 15
18. The plant according to claim 17, comprising an ammonia unit (8), where ammonia is produced by direct reaction of hydrogen and nitrogen; and wherein the oxygen generation unit (7) is defined by an air separation unit, in particular a cryogenic air separation unit, of the ammonia unit (8). 20
19. The plant according to one of claims 13 to 18, wherein the oxy-combustion unit (3) is fed with an oxygen stream containing at least about 80%vol, preferably at least 90%vol, of oxygen. 25
20. The plant according to one of claims 13 to 19, comprising an energy recovery unit (13), connected to the oxy-combustion unit (3) by an exhaust line (11) which conveys to the energy recovery unit (13) exhausts produced in the oxy-combustion unit (3) and is configured to recover thermal energy from said exhausts and produce steam and/or electric energy. 30
21. The plant according to claim 20, comprising an exhaust recirculation line (16) which connects the energy recovery unit (13) to the oxy-combustion unit (3) and/or to the energy recovery unit (13) itself for recirculating a part of exhausts to the oxy-combustion unit (3) and/or to the energy recovery unit (13). 35
22. The plant according to one of claims 13 to 21, comprising a recovery section (20) configured so as to recover, i.e. separate, from at least a part of exhausts containing and produced in the oxy-combustion unit (3). 40
23. The plant according to claim 22, wherein the recovery section (20) comprises an exhaust treating unit (21), a condensation unit (22), and a purification and compression unit (15), connected to the energy recovery unit (13) and to each other, in series, by respective portions (11a, 11b, 11c) of an exhaust line (11). 45

## Patentansprüche

1. Verfahren zur Herstellung von Harnstoff, das einen Schritt zur Synthese von Harnstoff durch Reaktion von Ammoniak und Kohlendioxid umfasst, wobei zumindest ein Teil des Kohlendioxids für die Harnstoff-Reaktionssynthese in einem Oxy-Verbrennungsverfahren hergestellt wird; **dadurch gekennzeichnet, dass** das Oxy-Verbrennungsverfahren ein flammenloses Oxy-Verbrennungsverfahren ist. 5
2. Verfahren nach Anspruch 1, wobei das Oxy-Verbrennungsverfahren ein flammenloses und unter Druck stehendes Oxy-Verbrennungsverfahren ist. 10
3. Verfahren nach Anspruch 1 oder 2, wobei das Oxy-Verbrennungsverfahren bei einer Verbrennungstemperatur in einem Bereich von zwischen etwa 800 und etwa 1800 °C, vorzugsweise zwischen etwa 1000 und etwa 1500 °C, durchgeführt wird. 15
4. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Oxy-Verbrennungsverfahren bei einem Druck in einem Bereich von zwischen 0 und 40 Bar G durchgeführt wird. 20
5. Verfahren nach einem der vorhergehenden Ansprüche, wobei dem Oxy-Verbrennungsverfahren Sauerstoff zugeführt wird, der in einem Schritt der Sauerstoffherzeugung, insbesondere in einem Luftabscheidungsschritt, hergestellt wird. 25
6. Verfahren nach einem der vorhergehenden Ansprüche, wobei zumindest ein Teil des Ammoniaks für die Harnstoffsynthesereaktion in einem Schritt der Synthese von Ammoniak durch direkte Reaktion von Wasserstoff und Stickstoff hergestellt wird, wobei der Stickstoff in einem Luftabscheidungsschritt zusammen mit Sauerstoff hergestellt wird; und wobei ein Teil des in dem Luftabscheidungsschritt hergestellten Sauerstoffs dem Oxy-Verbrennungsverfahren zugeführt wird. 30
7. Verfahren nach einem der vorhergehenden Ansprüche, wobei dem Oxy-Verbrennungsverfahren eine Sauerstoffströmung zugeführt wird, die mindestens etwa 80 Vol.-%, vorzugsweise mindestens etwa 90 Vol.-%, Sauerstoff enthält. 35
8. Verfahren nach einem der vorhergehenden Ansprüche, das einen Energierückgewinnungsschritt umfasst, in dem Wärmeenergie von in dem Oxy-Verbrennungsprozess erzeugten Abgasen zur Erzeugung von Dampf und/oder elektrischer Energie rückgewonnen wird. 40
9. Verfahren nach Anspruch 8, das einen Schritt des Rückführens eines Teils der Abgase zu dem Oxy- 45

Verbrennungsprozess und/oder zu dem Energie-rückgewinnungsschritt umfasst.

10. Verfahren nach einem der vorhergehenden Ansprüche, das einen Schritt des Rückgewinnens, d. h. Abscheidens, einer CO<sub>2</sub>-Strömung von zumindest einem Teil von Abgasen umfasst, die CO<sub>2</sub> enthalten und in dem Oxy-Verbrennungsprozess erzeugt werden.
11. Verfahren nach Anspruch 10, wobei der Schritt des Rückgewinnens von CO<sub>2</sub> die folgenden Schritte umfasst: Behandeln der Abgase zum Entfernen von Schadstoffen von den Abgasen, Kondensieren der Abgase durch Entfernen von Kondenswasser und Erhalten einer CO<sub>2</sub>-Strömung und Reinigen und Verdichten der CO<sub>2</sub>-Strömung.
12. Verfahren nach einem der vorhergehenden Ansprüche, wobei in den durch den Oxy-Verbrennungsprozess erzeugten Abgasen ein Überschuss an Sauerstoff vorhanden ist, der so in der der Harnstoff-Synthesereaktion zugeführten CO<sub>2</sub>-Strömung aufrechterhalten wird, dass er als ein Passivierungsmittel wirkt.
13. Harnstoff-Produktionsanlage (1), die eine Harnstoffeinheit (2) zum Erzeugen von Harnstoff durch Reaktion von Ammoniak und Kohlendioxid und eine Oxy-Verbrennungseinheit (3) umfasst, in der an die Harnstoffeinheit (2) zur Zufuhr zur Harnstoff-Synthesereaktion von Ammoniak und Kohlendioxid zu sendendes Kohlendioxid hergestellt wird; **dadurch gekennzeichnet, dass** die Oxy-Verbrennungseinheit (3) eine flammenlose Oxy-Verbrennungseinheit ist, die eine flammenlose Brennkammer umfasst, die so ausgestaltet ist, dass sie ein flammenloses Oxy-Verbrennungsverfahren einer Kohlenstoffzufuhr durchführt.
14. Anlage nach Anspruch 13, wobei die Oxy-Verbrennungseinheit (3) eine flammenlose und unter Druck stehende Oxy-Verbrennungseinheit ist und die Brennkammer unter Druck steht.
15. Anlage nach Anspruch 13 oder 14, wobei die Brennkammer bei einer Verbrennungstemperatur in einem Bereich zwischen etwa 800 und etwa 1800 °C, vorzugsweise zwischen etwa 1000 und etwa 1500 °C, betrieben wird.
16. Anlage nach einem der Ansprüche 13 bis 15, wobei die Brennkammer bei einem Druck im Bereich von zwischen etwa 0 und 40 Bar G betrieben wird.
17. Anlage nach einem der Ansprüche 13 bis 16, wobei die Oxy-Verbrennungseinheit (3) mit einer Sauerstoff-Erzeugungseinheit (7), insbesondere einer

Luftabscheidungseinheit, verbunden ist, die mit der Oxy-Verbrennungseinheit (3) durch eine Sauerstoff-Zufuhrleitung (5) zum Zuführen von Sauerstoff zu der Oxy-Verbrennungseinheit (3) verbunden ist.

18. Anlage nach Anspruch 17, die eine Ammoniakereinheit (8) umfasst, wobei Ammoniak durch direkte Reaktion von Sauerstoff und Stickstoff erzeugt wird; und wobei die Sauerstoff-Erzeugungseinheit (7) durch eine Luftabscheidungseinheit, insbesondere eine kryogene Luftabscheidungseinheit, der Ammoniakereinheit (8) definiert ist.
19. Anlage nach einem der Ansprüche 13 bis 18, wobei der Oxy-Verbrennungseinheit (3) eine Sauerstoffströmung zugeführt wird, die mindestens etwa 80 Vol.-%, vorzugsweise mindestens 90 Vol.-%, Sauerstoff enthält.
20. Anlage nach einem der Ansprüche 13 bis 19, die eine Energierückgewinnungseinheit (13) umfasst, die durch eine Abgasleitung (11), die der Energierückgewinnungseinheit (13) in der Oxy-Verbrennungseinheit (3) erzeugte Abgase zuführt, mit der Oxy-Verbrennungseinheit (3) verbunden ist und so ausgestaltet ist, dass sie Wärmeenergie von den Abgasen rückgewinnt und Dampf und/oder elektrische Energie erzeugt.
21. Anlage nach Anspruch 20, die eine Abgasrückführungsleitung (16) umfasst, die die Energierückgewinnungseinheit (13) mit der Oxy-Verbrennungseinheit (3) und/oder mit der Energierückgewinnungseinheit (13) selbst zum Rückführen eines Teils von Abgasen zu der Oxy-Verbrennungseinheit (3) und/oder der Energierückgewinnungseinheit (13) verbindet.
22. Anlage nach einem der Ansprüche 13 bis 21, die einen CO<sub>2</sub>-Rückgewinnungsabschnitt (20) umfasst, der so ausgestaltet ist, dass er CO<sub>2</sub> von zumindest einem Teil von Abgasen, die CO<sub>2</sub> enthalten und in der Oxy-Verbrennungseinheit (3) erzeugt werden, rückgewinnt, d. h. abscheidet.
23. Anlage nach Anspruch 22, wobei der CO<sub>2</sub>-Rückgewinnungsabschnitt (20) eine Abgasbehandlungseinheit (21), eine Kondensationseinheit (22) und eine Reinigungs- und Verdichtungseinheit (15) umfasst, die mit der Energierückgewinnungseinheit (13) und einander durch entsprechende Abschnitte (11a, 11b, 11c) einer Abgasleitung (11) in Reihe verbunden sind.

## Revendications

1. Procédé de production d'urée comprenant une éta-



- pe de synthèse d'urée par réaction d'ammoniac et de dioxyde de carbone, au moins une partie du dioxyde de carbone pour la synthèse de réaction d'urée étant produite lors d'un procédé d'oxy-combustion ; **caractérisé en ce que** le procédé d'oxy-combustion est un procédé d'oxy-combustion sans flamme.
2. Procédé selon la revendication 1, dans lequel le procédé d'oxy-combustion est un procédé d'oxy-combustion sans flamme et sous pression.
  3. Procédé selon la revendication 1 ou 2, dans lequel le procédé d'oxy-combustion est réalisé à une température de combustion dans la plage entre environ 800 et environ 1800 °C, de préférence entre environ 1000 et environ 1500 °C.
  4. Procédé selon une des revendications précédentes, dans lequel le procédé d'oxy-combustion est réalisé à une pression dans la plage entre 0 et 40 bar g.
  5. Procédé selon une des revendications précédentes, dans lequel le procédé d'oxy-combustion est alimenté en oxygène produit lors d'une étape de génération d'oxygène, en particulier lors d'une étape de séparation d'air.
  6. Procédé selon une des revendications précédentes, dans lequel au moins une partie de l'ammoniac pour la réaction de synthèse d'urée est produite lors d'une étape de synthèse d'ammoniac par réaction directe d'hydrogène et d'azote, l'azote étant produit lors d'une étape de séparation d'air avec l'oxygène ; et dans lequel une partie de l'oxygène produit lors d'une étape de séparation d'air alimente le procédé d'oxy-combustion.
  7. Procédé selon une des revendications précédentes, dans lequel le procédé d'oxy-combustion est alimenté en un flux d'oxygène contenant au moins environ 80 % en volume, de préférence au moins 90 % en volume, d'oxygène.
  8. Procédé selon une des revendications précédentes, comprenant une étape de récupération d'énergie, dans laquelle de l'énergie thermique est récupérée des échappements produits lors du procédé d'oxy-combustion pour produire de la vapeur et/ou de l'énergie électrique.
  9. Procédé selon la revendication 8, comprenant une étape de remise en circulation d'une partie des échappements au procédé d'oxy-combustion et/ou à l'étape de récupération d'énergie.
  10. Procédé selon une des revendications précédentes, comprenant une étape de récupération, c'est-à-dire de séparation, d'un flux de CO<sub>2</sub> d'au moins une partie d'échappements contenant du CO<sub>2</sub> et produits lors du procédé d'oxy-combustion.
  11. Procédé selon la revendication 10, dans lequel l'étape de récupération de CO<sub>2</sub> comprend les étapes consistant à : traiter les échappements pour éliminer les polluants des échappements, condenser les échappements en éliminant l'eau de condensat et en obtenant un flux de CO<sub>2</sub>, et purifier et comprimer le flux de CO<sub>2</sub>.
  12. Procédé selon une des revendications précédentes, dans lequel dans les échappements produits par le procédé d'oxy-combustion se trouve un excès d'oxygène qui est maintenu dans le flux de CO<sub>2</sub> acheminé jusqu'à la réaction de synthèse d'urée, pour servir d'agent de passivation.
  13. Installation de production d'urée (1), comprenant une unité d'urée (2) pour produire de l'urée par réaction d'ammoniac et de dioxyde de carbone, et d'une unité d'oxy-combustion (3) dans laquelle du dioxyde de carbone est produit pour être envoyé à l'unité d'urée (2) pour alimenter la réaction de synthèse d'urée à partir d'ammoniac et de dioxyde de carbone ; **caractérisée en ce que** l'unité d'oxy-combustion (3) est une unité d'oxy-combustion sans flamme comprenant une chambre de combustion sans flamme configurée de manière à effectuer un procédé d'oxy-combustion sans flamme d'un apport de carbone.
  14. Installation selon la revendication 13, dans laquelle l'unité d'oxy-combustion (3) est une unité d'oxy-combustion sans flamme et sous pression et ladite chambre de combustion est mise sous pression.
  15. Installation selon la revendication 13 ou 14, dans laquelle la chambre de combustion fonctionne à une température de combustion dans la plage entre environ 800 et environ 1800 °C, de préférence entre environ 100 et environ 1500 °C.
  16. Installation selon une des revendications 13 à 15, dans laquelle la chambre de combustion fonctionne à une pression dans la plage entre 0 et 40 bar g.
  17. Installation selon une des revendications 13 à 16, dans laquelle l'unité d'oxy-combustion (3) est reliée à une unité de génération d'oxygène (7), en particulier une unité de séparation d'air, reliée à l'unité d'oxy-combustion (3) par une conduite d'alimentation en oxygène (5) pour acheminer l'oxygène jusqu'à l'unité d'oxy-combustion (3).
  18. Installation selon la revendication 17, comprenant une unité d'ammoniac (8), où l'ammoniac est produit par réaction directe d'hydrogène et d'azote ; et dans

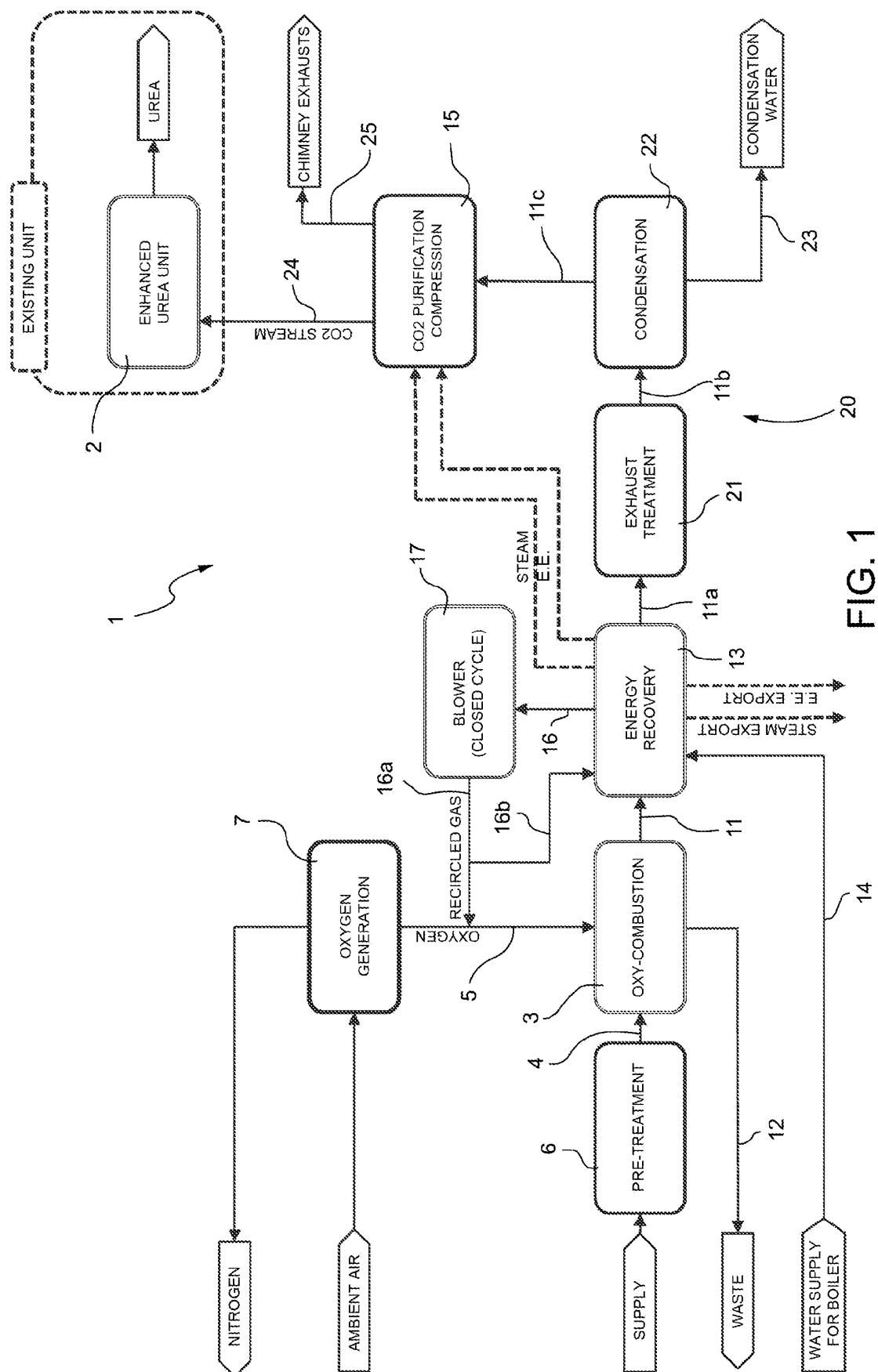
laquelle l'unité de génération d'oxygène (7) est définie par une unité de séparation d'air, en particulier une unité de séparation d'air cryogénique, de l'unité d'ammoniac (8) .

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- 19.** Installation selon une des revendications 13 à 18, dans laquelle l'unité d'oxy-combustion (3) est alimentée en un flux d'oxygène contenant au moins environ 80 % en volume, de préférence au moins 90 % en volume, d'oxygène. 10
- 20.** Installation selon une des revendications 13 à 19, comprenant une unité de récupération d'énergie (13), reliée à l'unité d'oxy-combustion (3) par une conduite d'échappement (11) qui transporte jusqu'à l'unité de récupération d'énergie (13) les échappements produits dans l'unité d'oxy-combustion (3) et est configurée pour récupérer l'énergie thermique provenant desdits échappements et produire de la vapeur et/ou de l'énergie électrique. 15 20
- 21.** Installation selon la revendication 20, comprenant une conduite de remise en circulation d'échappement (16) qui relie l'unité de récupération d'énergie (13) à l'unité d'oxy-combustion (3) et/ou à l'unité de récupération d'énergie (13) elle-même pour remettre en circulation une partie d'échappements vers l'unité d'oxy-combustion (3) et/ou vers l'unité de récupération d'énergie (13). 25 30
- 22.** Installation selon une des revendications 13 à 21, comprenant une section de récupération de CO<sub>2</sub> (20) configurée de manière à récupérer, c'est-à-dire séparer, du CO<sub>2</sub> d'au moins une partie d'échappements contenant du CO<sub>2</sub> et produits dans l'unité d'oxy-combustion (3). 35
- 23.** Installation selon la revendication 22, dans laquelle la section de récupération de CO<sub>2</sub> (20) comprend une unité de traitement d'échappement (21), une unité de condensation (22), et une unité de purification et de compression (15), reliées à l'unité de récupération d'énergie (13) et les unes aux autres, en série, par des portions (11a, 11b, 11c) respectives d'une conduite d'échappement (11). 40 45

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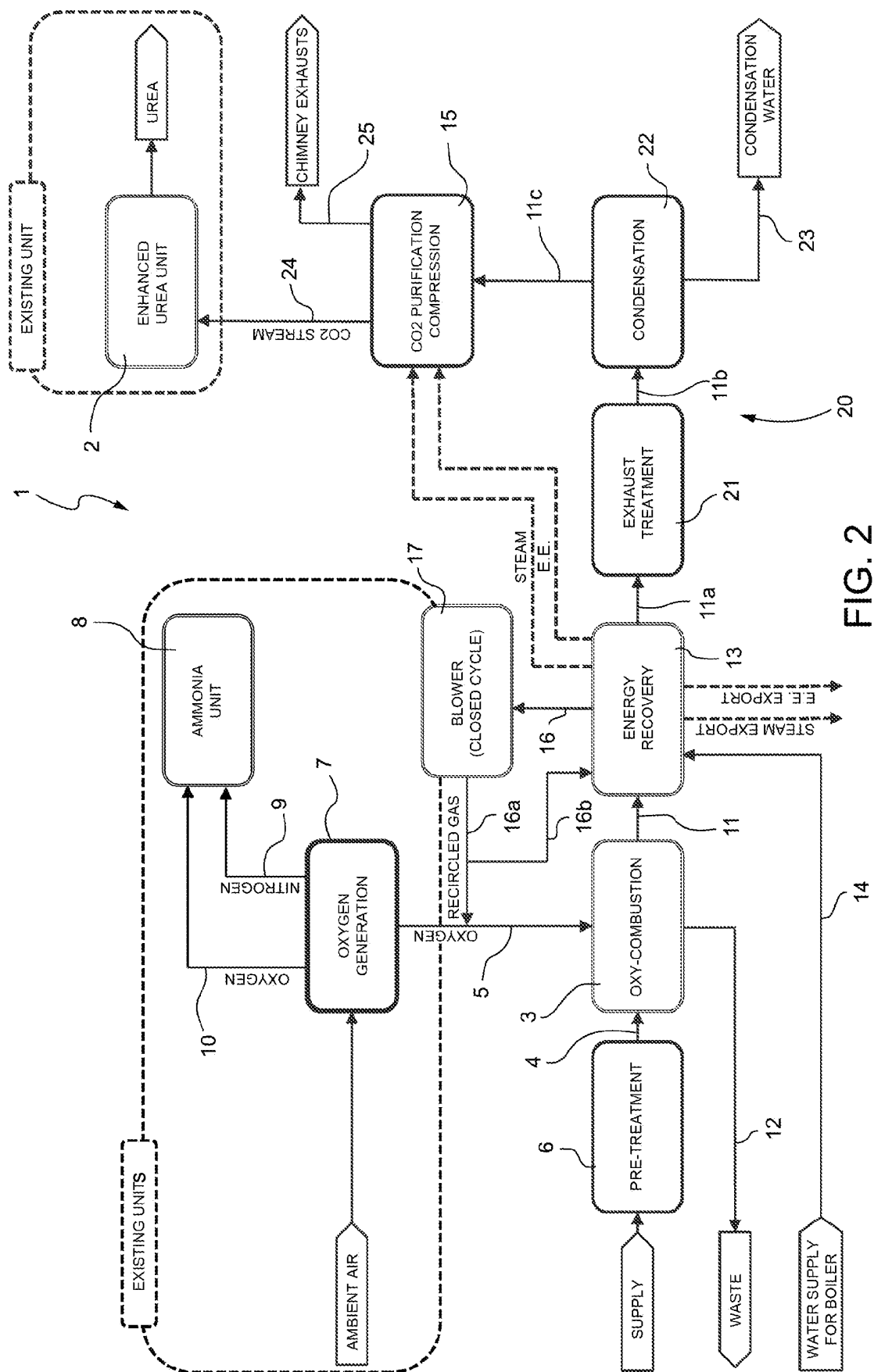


FIG. 2

**REFERENCES CITED IN THE DESCRIPTION**

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