



(11) **EP 4 772 793 A2**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
08.07.2026 Bulletin 2026/28

(51) International Patent Classification (IPC):
F23D 1/04 (2006.01)

(21) Application number: **26173688.8**

(52) Cooperative Patent Classification (CPC):
F23C 3/002; F23C 9/003; F23C 9/006; F23D 1/04; F23C 2900/03009

(22) Date of filing: **29.06.2023**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR

- **DE GOEY, Laurentius Philippus Hendrika**
5612 AE Eindhoven (NL)
- **SHOSHYN, Yuriy**
5612 AE Eindhoven (NL)
- **SPEE, Tim**
5612 AE Eindhoven (NL)

(30) Priority: **07.07.2022 NL 2032415**

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
23742429.6 / 4 551 866

(74) Representative: **Jilderda, Anne Ayolt**
LIOC Patents & Trademarks
Zwaanstraat 31 L
5651 CA Eindhoven (NL)

(71) Applicant: **Technische Universiteit Eindhoven**
5612 AE Eindhoven (NL)

(72) Inventors:
• **BAIGMOHAMMADI, Mohammadreza**
5612 AE Eindhoven (NL)

Remarks:

This application was filed on 21.04.2026 as a divisional application to the application mentioned under INID code 62.

(54) **A BURNER AND A PROCESS FOR COMBUSTING METAL POWDER**

(57) A burner (1) for combusting metal powder, particularly iron powder, comprising a combustion chamber (2) containing a combustion space for holding a combustion flame during operation, the combustion chamber having an air inlet (3), a metal powder inlet (4), and an exhaust gas outlet (5), characterized in that the combustion chamber (2) has a recirculation channel (7) for recirculating exhaust gases, the recirculation channel (7) being in communication with the combustion space within said combustion chamber (2), and the recirculation channel (7) intersecting with the air inlet (3).

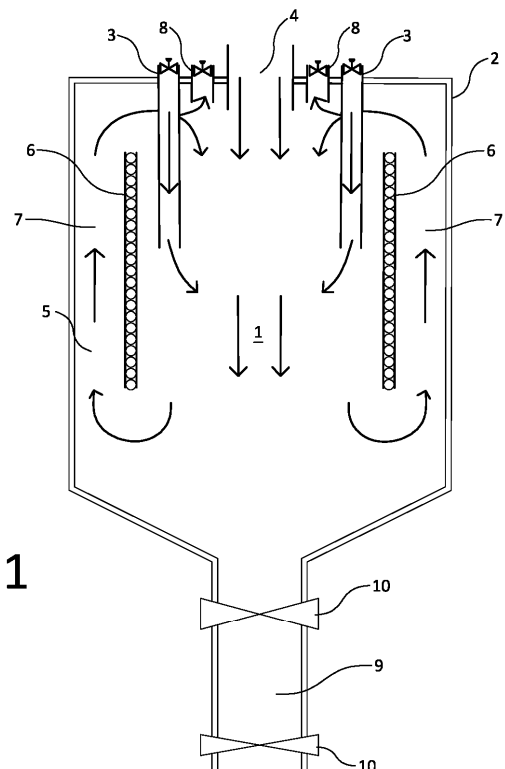


Fig.1

Description

[0001] The current invention relates to a burner for combusting a metal containing powder, particularly iron powder, comprising a combustion chamber having a combustion space for holding a combustion flame during operation, the combustion chamber having at least one air inlet, a powder inlet, and at least one exhaust gas outlet. The invention moreover relates to a process for combusting a metal containing powder, said process comprising: providing a combustion chamber, supplying metal containing powder into the combustion chamber, supplying fresh air, and allowing said powder to ignite.

[0002] Fossil fuels are known to be unsustainable and damaging to the environment. Sustainable energy carriers, for example, hydrogen and ammonia, might provide a suitable alternative to fossil fuels. Some of the benefits of a combustion of hydrogen include that it does not produce carbon dioxide and that it is a sustainable carrier of energy, especially when produced with renewable energy. Using hydrogen can therefore reduce carbon dioxide emissions. Hydrogen is also a clean carrier of energy with no adverse side-effects to the environment since the production of hydrogen only requires water and heat.

[0003] In the further development of hydrogen as an energy carrier, production, storage and use of hydrogen will play an important role. Currently, hydrogen is being delivered to sites with pipelines, as liquid hydrogen or as highly compressed gas. Transporting hydrogen as a cryogenic liquid or as compressed gas are capital and energy-intensive processes which result in an increase in the cost of hydrogen. Consequently, a need developed for a storage system that can store energy and which allows for ease of transportation thereof. Research has been done towards different ways of storing energy, including the use of reversible chemical reactions and absorption of hydrogen by various metals and metal alloys to form metal hydrides.

[0004] In this case the focus is on the use of metal as an energy carrier in the quest to resolving the above-mentioned important missing elements in the energy transition to long-term and large-scale storage of sustainable energy without emission of carbon dioxide. In order to gain energy from metal as an energy carrier, the metal is being combusted to form metal oxide. The delivered metal oxide may subsequently be reduced to the starting metal again in a energy consuming process that stores said energy. To ensure the sustainability of the process, the process needs to be a cyclic conversion process in which both combustion and reduction are repeatable, stable, and clean.

[0005] There is currently no applicable oxidation process that is well controllable and stable, including controlled ignition of the metal. No process currently available allows for fast and highly efficient conversion of metal particles to easy-to-capture metal oxide particles with a minimal amount of fouling and with minimal loss of

material. The available processes also do not provide for minimal unwanted emissions of pollutant gases, including carbon dioxide, nitrogen oxide, in the form of smoke, dust or nano-particle matter.

[0006] Particularly, using normal air at lean conditions, the combustion of metal powders result in ignited iron particles that burn extremely fast. As a consequence particle temperatures may overshoot gas mixture temperatures to values that lead to excessive evaporation of the metal and metal oxide and, therefore, may lead to loss of mass of the individual metal particles. The evaporated metal or metal oxide mass finally ends up in smoke and nano-particle matter. This matter can be captured, for example, with absolute filters, to avoid smoke emissions but it might still lead to fast filter contamination and blockage. This mass cannot easily be used in subsequent steps of a reduction-combustion cycle. Excessive evaporation is therefore detrimental to this cycle in the recycling of metal powder.

[0007] The present invention has for its object, among others, to provide an improved burner and process for the combustion of metal powder, particularly to be used as a recyclable energy carrier.

[0008] In order to achieve the stated object, a burner of the type described in the opening paragraph, according to the invention, is characterized in that the combustion chamber has a re-circulation channel for recirculating exhaust gases, the re-circulation channel leading to the combustion space via at least one return channel within said combustion chamber, in that the powder inlet opens into said return channel, and in that said at least one air inlet opens into said return channel downstream of said powder inlet. As a result the fresh powder fuel is first mixed with (partly cooled) re-circulating exhaust gases, also generally referred to as flue gases or as combustion gases, before being mixed with fresh air a little further downstream.

[0009] Moreover, the powder fuel is injected initially in relatively oxygen-poor, i.e. significantly sub-stoichiometric, recirculating exhaust gases, which results in an extremely rich fuel mixture and as a consequence may lead to only a partial combustion of the metal. This appears beneficial for stabilizing the flame by retarding the heat dissipation within the combustion space. Fresh, relatively oxygen rich air may be scarcely introduced as needed, particularly a little further downstream of this first contact of the injected powder with said residual oxygen of the exhaust gases.

[0010] The supplied oxygen is particularly delivered only slightly in excess of a stoichiometric quantity to allow a complete combustion of the introduced metal. The exhaust gases, containing a slight amount of residual oxygen, are again re-circulated to complete a next cycle. Heat is extracted from the re-circulating exhaust gases on its way back to the combustion chamber by suitable heat exchange means such that the gas temperature is maintained below a stable level. This step-wise combustion and heat extraction aids in lowering the flame tem-

perature and stabilizing the combustion process and lowering the flame temperatures.

[0011] A process for combusting metal powder as described in the opening paragraph, according to the invention is characterized by capturing exhaust gases from a combustion space within said combustion chamber, recirculating said exhaust gases along a re-circulation path to said combustion space, introducing said metal powder into said re-circulation path, and dosing said fresh air into said re-circulation path to supplement said exhaust gases as needed for a substantially complete combustion of said metal powder.

[0012] The invention is thereby based on the recognition that the hot exhaust gases have still a residual oxygen contents after the metal powder has consumed part of the oxygen present in the air supply. By injecting metal containing powder in the re-circulated hot exhaust gases an ignition and partial combustion of the metal may be established already at the front of the combustion space. Complete combustion is effected only later, more downstream by means of an appropriate dosed intake of an amount of fresh air that supplements the oxygen contents of the recirculating exhaust gases, preferably slightly in excess of a stoichiometric need of the fuel powder. This will create a self-sustained combustion process that can be kept stable and controlled.

[0013] Particularly to that end, a preferred embodiment the process according to the invention is characterized in that said fresh air supply is tuned to maintain a temperature inside the combustion space beyond an auto-ignition temperature of said metal and well below a boiling temperature of said metal, preferably at least a few to several hundred degrees below said boiling point. This ensures that hardly any metal will evaporate, which would otherwise would give rise to undesired loss of powder material. On the other hand the temperature beyond the auto-ignition temperature of the metal concerned allows for a self-sustained combustion process that does not require an external heat source. Particularly the hot exhaust gases that are re-circulated pre-heat the metal fuel that is being introduced constantly to beyond its auto-ignition temperature such that the combustion process continues autonomically in a controlled and stable manner.

[0014] In practice it has been proven that a stable and self-contained combustion of metal powder may be realized by a particular embodiment of the process according to the invention that is characterized in that said fresh air supply is tuned to maintain an oxygen concentration within said combustion space below a level of between 10% and 15%. The majority of this oxygen content will be consumed by the combustion process.

[0015] The exhaust gases, recirculating towards the powder inlet, consequently, will have a significant lower residual oxygen concentration after combustion. Such residual oxygen contents particularly lies below 5%. Any fresh air supply is preferably tuned to create an oxygen concentration slightly in excess of a stoichiometric need

for a complete oxidation of the fuel within the powder.

[0016] Preferably, the oxygen level near the ignition front and around the primary combustion phase towards metal oxide may be kept low enough, i.e. less than 10%, to keep particle temperatures well below any significant evaporation temperature of the metal or metal oxide, avoiding consequential metal mass loss of the individual particles as a result of smoke or other nano-particles. Any excess heat in the re-circulating hot exhaust gases is preferably removed by allowing said exhaust gases to cool down within said re-circulation path and to mix with said metal powder at a reduced temperature.

[0017] Evaporation may be largely suppressed to a value of less than 0.1% mass loss if the combustion temperature is maintained beyond an auto-ignition temperature of said powder and well below a boiling temperature of the metal within said powder. For iron powder said fresh air supply is preferably tuned to maintain a temperature inside the combustion space between 1050 K and 2150 K. In that case, the combustion process may be controlled in the condensed phases (solid and liquid) without uncontrolled temperature overshooting that may lead to partial evaporation and consequential mass loss of particles.

[0018] To ensure a sufficiently rich initial powder fuel to oxygen mixture, a further preferred embodiment of the process according to the invention is characterized in that the exhaust gases are captured having a residual oxygen concentration below 5%. Depending on the actual oxygen depletion of the exhaust gases, a mixing ratio between the re-circulated exhaust gases and the intake of fresh air may be regulated to stabilize the combustion process. Satisfactory results have been achieved in practice in a further particular embodiment of the process according to the invention characterized in that the exhaust gases are mixed with said fresh air in ratio exceeding 1:1, preferably in a ratio of about 1,5:1, and in that any excess of said exhaust gases is evacuated from said combustion chamber.

[0019] In order to be able to control the intake of fresh air a preferred embodiment of the burner according to the invention may advantageously be used, said burner being characterized in that said air inlet has a controllable valve. This controllable air intake valve may be electronically controllable by a control unit that may be coupled to a temperature sensor mounted inside or at least thermally coupled to the combustion space or to an oxygen sensor to control the intake of fresh air depending on the actual flame temperature or oxygen level.

[0020] At least part of said fresh air may be introduced in said re-circulation path upstream of said introduction of said metal powder. At least part of said fresh air may be introduced in said re-circulation path downstream of said introduction of said metal powder. Said fresh air may be injected by suitable injector means.

[0021] An excess of exhaust gases may be evacuated through the exhaust gas outlet of the burner. In order to be able to regulate the fraction of exhaust gases to be re-

circulated and the fraction to be expelled, a further preferred embodiment of the burner according to the invention is characterized in that the exhaust gas outlet has a controllable valve. This controllable outlet valve may be electronically controllable by a control unit that is coupled to a temperature sensor mounted inside or at least thermally coupled to the combustion space or to an oxygen sensor to control the fraction of remaining re-circulating exhaust gases depending on the actual flame temperature or oxygen level.

[0022] Particularly a temperature sensor or an oxygen sensor may be used to monitor a temperature or oxygen concentration of the combustion flame in the combustion chamber. The sensor may be in communication with a control unit, the control unit controlling a flow through the valve in the air inlet and the valve in the exhaust gas outlet. The valves may then correspondingly be opened or closed to allow for more or less flow through the fresh air inlet and/or exhaust gas outlet to ensure that the temperature of the combustion flame remains between the metal powder auto-ignition temperature and well below its boiling point.

[0023] During the combustion process, a stabilization of gaseous, liquid, or solid fuel flames is generally governed by the presence of pre-evaporated gaseous fuel fragments. Mixing of the gaseous fuel fragments with oxygen leads to a premixed or non-premixed flame establishment and propagation in or near the boundary layers of walls at a burner mouth or objects in a flow near the burner mouth. Radiation and heat transfer by convection and diffusion might control this pre-evaporation process. When using metal containing powder as a fuel, such evaporation may be held negligible by means of the process according to the invention.

[0024] To the latter end, a further preferred embodiment of the process according to the invention is characterized in that the metal containing powder comprises predominantly metal particles having a size of at least 10 micron. Flame front establishment and flame propagation by mutual particle ignition without a supporting gaseous component appears to be sufficiently slow for the metal powder if the constituent powder particles have predominantly a relatively large surface-to-volume ratio.

[0025] The combustion process appears stable and well controllable if the particles have predominantly a size in excess of 10 micron, meaning a size that is roughly equivalent to a spherical particle having a diameter of 10 micron. In that case less fuel-to-oxygen interface is offered and auto-ignition of individual particles takes place at a relatively elevated temperature, which retard the combustion process and the release of heat. Particularly high temperatures, that would otherwise lead to undesired evaporation and, therefore, mass loss, may very well be avoided.

[0026] Nitrogen oxides (NO_x) are generally formed based on prompt and thermal NO_x mechanisms. Super-equilibrium O-radical formation and high-temperature Zeldovich NO formation processes involve ra-

dical pools including O, H, and OH radicals to oxidize a small fraction of nitrogen in the air. As hydrogen atoms are not present in metal flames burning in dry air, a highly active radical pool with super-equilibrium O-radical concentrations is largely avoided or suppressed, as well as part of the Zeldovich thermal nitrogen oxides process. This largely suppresses the activated oxidation of nitrogen and, as such, the formation of nitrogen oxides. In the present case, flame temperatures are additionally reduced by controlled combustion and cooling of combustion products. Hence, a formation of nitrogen oxides may be suppressed in the process according to the invention to a level well below 10 mg/MJ, particularly even below 1 mg/MJ.

[0027] In a particular embodiment the process according to the invention is characterized in that a powder is used that comprises iron powder. In that case the burner according to the invention advantageously may be used for such combustion of iron powder. Iron powder is a high density energy carrier that is reusable and which does not emit carbon dioxide. Iron is moreover present worldwide on an abundant scale. Moreover, iron appears very well suitable in the process according to the invention as it exhibits a large operational window between the auto-ignition temperature and its boiling point of typically 900-1100 K and 3135 K respectively. A preferred embodiment of the process according to the invention is hence characterized in that a temperature inside the combustion space is maintained between 1050 K and 2150 K.

[0028] In order to allow for ease of collection of metal oxide masses formed in the combustion chamber, a further preferred embodiment of the burner according to the invention is characterized in that the combustion chamber has a combusted mass outlet, the combusted mass outlet being any one of the group consisting of: a channel, a conveyer belt, rollers, a chute, a cyclone and a door. A metal oxide masses may for instance be collected at a lower end of the combustion chamber after combustion. The guiding means may then be used for removing the metal oxide masses from the combustion chamber to an external collection area.

[0029] In order to gain the freed energy from the combustion process, a further embodiment of the burner according to the invention is characterized in that the combustion chamber is thermodynamically coupled to a heat exchanger. The collected heat may be used directly, for instance for ambient heating purposes, or may be converted to another form of energy, for instance kinetic energy or electricity.

[0030] A further particular embodiment of the burner according to the invention is characterized in that a screen separates said re-circulation channel from said combustion space within said combustion chamber over a part of a height of said combustion chamber. The screen particularly extends all around while keeping a distance to the walls of the combustion chamber to allow a re-circulation of the exhaust gases. The re-circulation channel extends from said combustion space to said

powder inlet through the space that is accordingly created in between the walls of the combustion chamber and said screen. The re-circulating exhaust gases in that case are allowed to flow over said screen in order to mix with the injected powder.

[0031] The re-circulating exhaust gases are still hot and cause the injected powder to ignite already at this initial stage. In this respect, a preferred embodiment of the burner according to the invention is characterized in that said screen comprises said at least one heat exchanger. By extracting heat from the re-circulating exhaust gases the final temperature before reaching the powder inlet may be maintained significantly below the boiling point of the metal contained in the powder in order to avoid evaporation. This gives an additional control over the burning process and aids in stabilizing the flame and reducing the NO_x output

A particularly practical setup is being obtained by a further particular embodiment of the burner according to the invention characterized in that said powder inlet extends through a roof of the combustion chamber, particularly a removable roof, and in that said combustion chamber has a upright orientation in which said powder inlet maintains a vertical relationship with said combustion space and a combusted mass outlet of said combustion space. As a consequence of gravitation the combusted mass will fall downwards towards said combusted mass outlet. The hot exhaust gases, on the other hand, may re-circulate based on convection. In a further embodiment the burner is characterized in that also said at least one air inlet and said at least one exhaust gas outlet extend through said roof.

[0032] The invention will now be further elucidated on the basis of an exemplary embodiment and accompanying drawings. In the drawings:

Figure 1 shows a schematic diagram of an embodiment of a burner according to the invention; and

Figure 2 shows a top view of the burner of figure 1.

[0033] It is noted that the drawing is purely schematic and not drawn to scale. Some dimensions in particular may be exaggerated to greater or lesser extent for the sake of clarity. Corresponding parts are designated in the figure with the same reference numeral.

[0034] An exemplary embodiment of a burner according to the invention is shown in figure 1. The burner comprises a combustion chamber 2. In this embodiment, the combustion chamber 2 is a generally cylindrical container with a substantially flat roof or hood at a top thereof and a conically-shaped lower end. However, in alternative embodiments the combustion chamber may have any suitable alternative size or shape. A central area in the combustion chamber 2 defines a combustion space 1 for holding a combustion flame.

[0035] Fuel to be combusted, in this case iron powder, enters the combustion chamber 2 through a metal fuel

inlet 4. The metal fuel inlet 4, in this case an iron powder inlet, extends centrally through the roof of the chamber 2. A dosing mechanism and storage container (not shown) may be mounted to this metal powder inlet 4 to offer a controlled supply of metal powder.

[0036] The burner further comprises three exhaust gas outlets 8 that extend through the roof of the combustion chamber 2. The gas outlets 8 are evenly spaced apart around the powder inlet 4, see also figure 2. If desired, one or more gas outlet/s 8 may extend all around the combustion chamber 2. Furthermore, six air inlets 3, also evenly spaced apart, extend into the roof of the combustion chamber 2 and around the gas outlets 8. Air is fed into the combustion chamber through the air inlets 3. The air inlets 3 are spaced apart from the gas outlet 8.

[0037] Both the exhaust gas outlets 8 and the fresh air inlets 3 may be provided with controllable valves that are electrically operable by means of a central processing unit or means (not shown). Such processing unit or means may particularly be coupled to a temperature or oxygen sensor mounted in or near the combustion space 1, or coupled to it, in order to regulate a fresh air intake and exhaust gas outlet in dependence of the combustion temperature and/or oxygen concentration within said combustion space 1. The control unit may also regulate dosing to the metal powder inlet 4 to control an intake of metal powder. In alternative embodiments any number of iron powder inlets 4 and/or air inlets 3 and/or gas outlets 8 may be included, and the metal powder inlet and air intake may be combined in a common concentric tubing or may be pre/mixed before entering the combustion chamber.

[0038] The combustion chamber 2 resides within outside walls 5 that also confine said combustion space 1. A vertical screen 6 extends parallel to said walls over part of their height to leave clearance at a bottom in open communication with said combustion space as well as at its top in open communication with the air inlets 3. As shown in the figures said screen 6 is concentric with the combustion chamber 2, extending all around, while leaving a space 7 to the outside wall 5 of the combustion chamber. This intermediate space 7 is part of a re-circulation channel for exhaust gases that is depicted schematically by corresponding arrows in figure 1. As shown, said re-circulation channel 7 extends vertically along part of an internal height of the combustion chamber 2 intersecting first with the mouth of the powder intake 4 and a little further downstream with the air inlet 3 that opens below a top of said screen 6 at a side of said screen 6 opposite said part of said intermediate space 7.

[0039] An exhaust gas re-circulation path is defined in the combustion chamber 2 as illustrated in the figure by corresponding arrows. The re-circulation path extends from the combustion space 1 and upwardly through the intermediate space 7 to intersect with the mouth of the fuel inlet 4. The screen 6 that separates the combustion chamber 1 from this re-circulation path, comprises a thermal heat exchanger that extracts heat from the re-

circulating exhaust gases. The partly cooled exhaust gases merge with the intake of fresh metal fuel powder from the powder inlet 4, while a controllable valve in the exhaust gas outlet 8 controls an amount (if any) of exhaust gases exiting the combustion chamber 2 through said outlet. The oxygen poor but still sufficiently hot exhaust gases still contain a small amount of oxygen and already ignite the fresh powder entering the combustion chamber 2.

[0040] A controllable valve in each exhaust gas outlet 8 controls an amount (if any) of exhaust gases exiting the combustion chamber 2 through said outlet 8. Air which enters the combustion chamber 2 through the air inlets 3 drag the exhaust gases in a downwards direction, effectively driving circulation of the exhaust gases. A controllable valve in each air inlet 3 controls the flow of air into the combustion chamber 2. The air entering the combustion chamber 2 mixes with the re-circulating hot exhaust gases and is consequently pre-heated before entering the combustion space 1. The re-circulation of the exhaust gases also allows for maintaining a low oxygen concentration in the metal fuel to air mixture that is being formed. The low oxygen concentration in the partly cooled exhaust gases particularly ensures flame stabilization of the combustion flame. Flame stabilization is particularly achieved when the temperature of the combustion flame is between the auto-ignition temperature of the metal powder and the boiling point of said metal.

[0041] In this example the burner shown in figures 1 and 2 are used for the combustion of iron powder. When iron powder enters the combustion chamber 2, the iron powder mixes first with the re-circulated exhaust gases before reaching the combustion space 1 in the combustion chamber. Fresh ambient air, entering the combustion chamber through the air inlet 3, merges similarly or only later downstream to mix with the re-circulated exhaust gases and iron powder. This effectively increases the oxygen concentration of the re-circulated exhaust gases, depending on the control of the intake valve of the air inlet 3. Due to a high re-circulation rate of the exhaust gases the re-circulated exhaust gases contain mainly nitrogen ($R-N_2 > 85\%$) and a relatively low fraction of remaining oxygen ($R-O_2 < 15\%$). The low oxygen concentration of the exhaust gas mixture ensures flame stabilization to ensure ignition of the iron powder particles whilst preventing boiling of the iron powder particles.

[0042] Before admixing with the fresh iron powder, the re-circulated hot exhaust gases are only partly cooled by ambient air, having a lower temperature than the exhaust gases, which mixes with the re-circulated exhaust gases. The remaining temperature of exhaust gases entrained with the iron powder, however, stays above the ignition temperature of iron powder. A global exhaust gas to fresh air ratio larger than 1 is established, and more specifically larger than 1.5. A gradual admixing of ambient air into the mixture of re-circulated exhaust gas and burning iron powder is established to enforce close to complete final oxidation of iron towards hematite.

[0043] The air and metal powder mixture flows downwards towards the lower end of the combustion chamber 2 and towards the flame front. The flame ignites the iron powder particles, combusting the iron powder to form iron oxide masses. The combustion of the iron powder releases the stored energy to be used in further processes. The temperature within the combustion space needs to be a temperature that allows for oxidation of the iron powder whilst preventing evaporation of the iron or iron oxide. Therefore, the temperature is kept roughly between 900 K and 2150 K. Immediate ignition of fresh iron powder in the re-circulated exhaust gases at the iron powder inlet allows for the establishment of an auto-ignition based flame near the iron powder inlet without any external support for flame stabilization.

[0044] The oxygen level of gases near the ignition front and around the primary combustion phase is kept low enough, particularly lower than 10%, to keep particle temperatures well below any significant evaporation of iron or iron oxide, avoiding consequential iron mass loss of the individual particles towards smoke or other nanoparticles. In practice such losses may be kept well below 0.1 %. Particularly it turns out possible to control the combustion process in the condensed phases (solid and liquid) without uncontrolled temperature overshooting that may lead to partial evaporation and consequential mass loss. Final gas temperatures (which are partly used to re-circulate back to the inlet) are well below the adiabatic temperature (specifically, slightly above the ignition temperature) to keep also NO_x emission formation ultra-low, i.e. well below 10 mg/MJ or even below 1 mg/MJ.

[0045] The heat exchanger extracts heat from the re-circulating exhaust gases. In this manner the final temperature of the recirculating exhaust gases before reaching the powder inlet may be maintained significantly below the boiling point of the metal contained in the powder in order to avoid evaporation. This gives an additional control over the burning process and aids in stabilizing the flame.

[0046] The iron oxide masses fall toward the conically shaped lower end of the combustion chamber 2 to be collected at an outlet 9 from where it can be harvested. The outlet 9 is preferably provided with a set of airtight locks 10 at opposite ends of a collection chute to prevent air entering the combustion chamber 2 through the outlet. The resulting iron oxide mass may be harvested for reuse by any suitable means. The outlet 9 can be provided with one or more of anyone of a group consisting of a channel, a conveyer belt, rollers, a chute and a door. In a further process, the harvested iron oxide masses can be recycled to form iron powder. The iron powder can then again be combusted to form iron oxide using the combustion burner described above.

[0047] Although the invention has been further elucidated and described above with reference to only several exemplary embodiments, it will be apparent that the invention is by no means limited thereto. On the contrary,

many variations and embodiments are still possible within the scope of the invention for the person with ordinary skill in the art.

[0048] Particularly, the burner may also have an external or further internal re-circulation flow of hot exhaust gases, or both, possibly containing (part of the) hot combusted oxide particles, back towards the initial burner inlet where fresh fuel in the form of new metal particles is entrained in this hot flow together with a controlled amount of fresh ambient air.

[0049] Also such external or further flow path of hot exhaust gases may be guided along a further heat exchanger to capture heat from the combustion process to be used for instance as process heat in an industrial process plant or for residential heating.

[0050] According to the embodiment shown in the figures fresh air is supplied downstream of the powder intake. Alternatively or additionally a dosed fresh air intake may also be provided upstream of the powder intake or substantially at the location of the powder intake to control the oxygen contents within the combustion chamber at selected or several instances.

[0051] In general the invention provides for a controlled and stable combustion process and burner for metal containing powdery fuel that uses oxygen poor recirculating hot exhaust gases as a primary source of oxygen to be supplemented and mixed with a dosed quantity of fresh air as needed for a satisfactory combustion.

Claims

1. A burner for combusting a metal containing powder, particularly iron powder, comprising a combustion chamber having a combustion space for holding a combustion flame during operation, the combustion chamber having at least one air inlet, a powder inlet, and at least one exhaust gas outlet, **characterized in that** the combustion chamber has a re-circulation channel for recirculating exhaust gases that leads back to the combustion space via at least one return channel within said combustion chamber, **in that** the powder inlet opens into said return channel, and **in that** said at least one air inlet opens into said return channel downstream of said powder inlet.
2. The burner according to claim 1, **characterised in that** at least one of said at least one air inlet and said at least one exhaust gas outlet has a controllable valve.
3. The burner according to claim 1 or 2, **characterized in that** the combustion chamber has a combusted mass outlet, the combusted mass outlet being any one of a group consisting of: a channel, a conveyer belt, rollers, a chute, a cyclone and a door.
4. The burner according to any one of claim 1, 2 and 3,

characterized in that the combustion chamber is thermodynamically coupled to at least one heat exchanger.

5. The burner according to claim 4, **characterized in that** a screen separates said re-circulation channel from said combustion space within said combustion chamber over a part of a height of said combustion chamber, wherein particularly said screen comprises said at least one heat exchanger.
6. The burner according to any one of the preceding claims, **characterized in that** said powder inlet extends through a roof of the combustion chamber, particularly a removable roof, and **in that** said combustion chamber has a upright orientation in which said powder inlet maintains a vertical relationship with said combustion space and a combusted mass outlet of said combustion space, wherein particularly said at least one air inlet and said at least one exhaust gas outlet extend through said roof.
7. A process for combusting a metal containing powder, said process comprising:
 - providing a combustion chamber;
 - supplying metal containing powder into the combustion chamber;
 - supplying fresh air, particularly maintaining an oxygen concentration within said combustion space below a level of between 10% and 15%;
 - allowing said powder to ignite;
 - capturing exhaust gases from a combustion space within said combustion chamber;
 - recirculating said exhaust gases along a re-circulation path to said combustion space, particularly with a residual oxygen concentration below 5%;
 - introducing said metal powder into said re-circulation path; and
 - dosing said fresh air into said re-circulation path to supplement said exhaust gases as needed for a substantially complete combustion of said metal powder.
8. The process according to claim 7, **characterized in that** said fresh air supply is tuned to maintain a temperature inside the combustion space beyond an auto-ignition temperature of said metal and well below a boiling temperature of said metal, preferably at least a few hundred degrees below said boiling point.
9. The process according to claim 7 or 8, **characterized in that** said exhaust gases are allowed to cool down within said re-circulation path and to mix with said metal powder at a reduced temperature.

10. The process according to claims 7, 8 or 9, **characterized in that** the exhaust gases are mixed with said fresh air in ratio exceeding 1:1, preferably in a ratio of about 1,5:1, and **in that** any excess of exhaust gases is evacuated from said combustion chamber. 5
11. The process according to anyone of claims 7 to 10, **characterized in that** at least part of said fresh air is introduced in said re-circulation path upstream of said introduction of said metal powder. 10
12. The process according to anyone of claims 7 to 11, **characterized in that** at least part of said fresh air is introduced in said re-circulation path downstream of said introduction of said metal powder. 15
13. The process according to anyone of claims 7 to 12, **characterized in that** the metal containing powder comprises predominantly metal particles having a size of at least 10 micron. 20
14. The process according to any one of claims 7 to 13, **characterized in that** said fresh air supply is tuned to suppress a formation of nitrogen oxides to a level below 10 mg/MJ, particularly below 1 mg/MJ. 25
15. The process according to anyone of claims 7 to 14, **characterized in that** a powder is used that comprises iron powder, wherein said fresh air supply is tuned to maintain a temperature inside the combustion space between 1050 K and 2150 K. 30

35

40

45

50

55

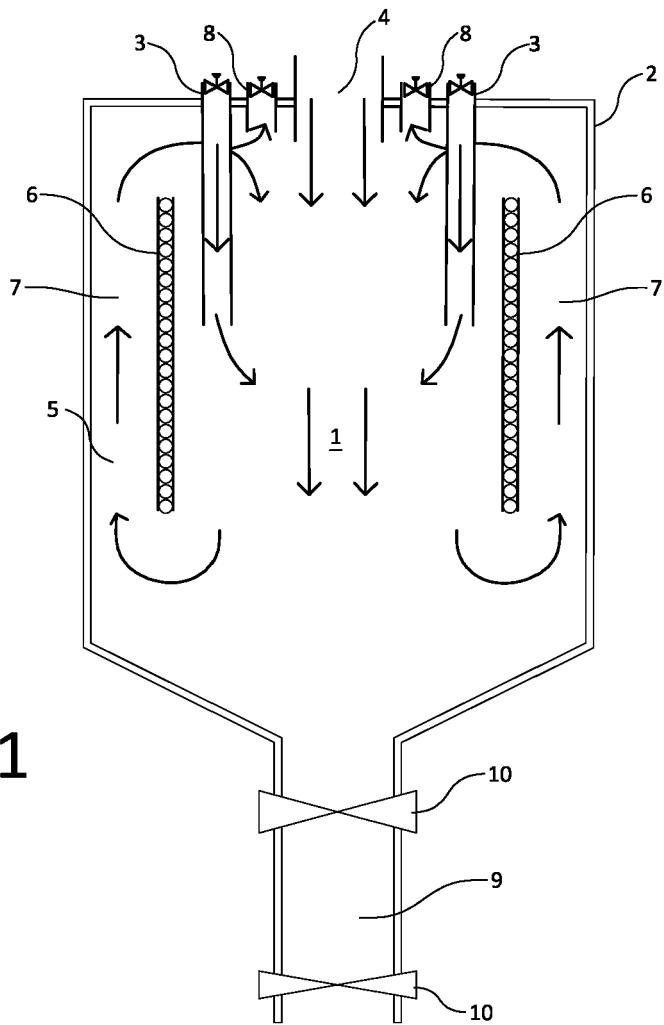


Fig.1

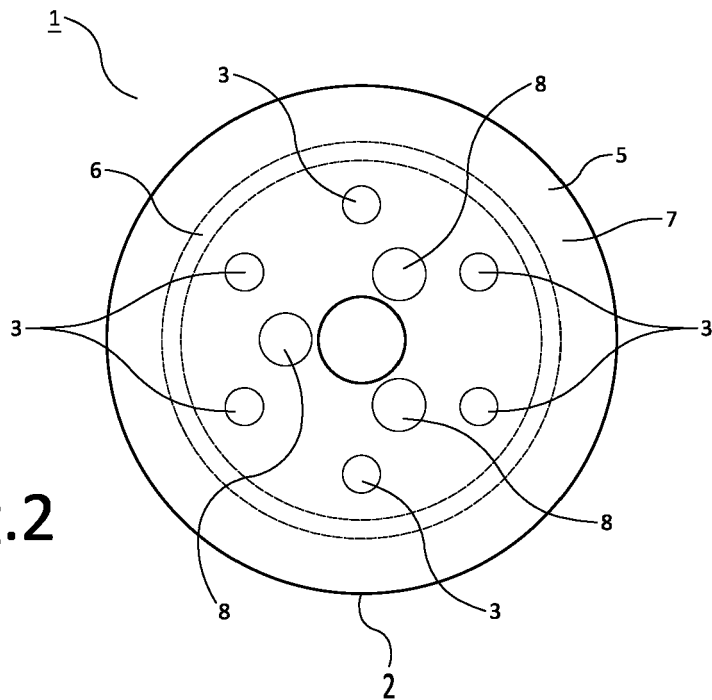


Fig.2