(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 February 2022 (24.02.2022)

(10) International Publication Number
WO 2022/037781 A1

(51) International Patent Classification:
C22B 5/12 (2006.01) *C22B 19/16* (2006.01)
C22B 7/02 (2006.01) *C22B 19/18* (2006.01)
C22B 7/04 (2006.01) *C22B 19/30* (2006.01)
C22B 13/02 (2006.01)

(21) International Application Number:
PCT/EP2020/073313

(22) International Filing Date:
20 August 2020 (20.08.2020)

(25) Filing Language: English

(26) Publication Language: English

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(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, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW,

(54) Title: A METHOD FOR SEPARATING ZINC FROM AN INDUSTRY PRODUCT USING A PYROMETALLURGICAL REACTION

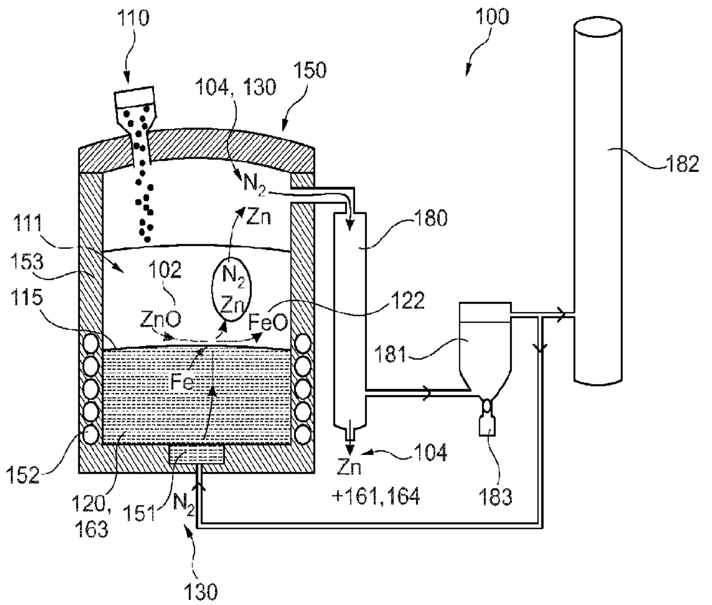

Fig. 2

(57) **Abstract:** A method for separating zinc from an industry product (110) is described, the method comprising: i) providing the industry product (110) which comprises oxidized zinc (102); ii) heating the industry product (110) so that the industry product (110) at least partially melts (111); iii) providing a reduced metal (120) to the industry product (110), thereby forming an interface (115) between the at least partially melted industry product (111) and the reduced metal (120); iv) providing a non-oxidizing gas (130) to the interface (115); v) performing a chemical reaction at the interface (115) between the at least partially melted industry product (111) and the reduced metal (120) in presence of the non-oxidizing gas (130), so that the oxidized zinc (102) is reduced (104) and the reduced metal (120) is oxidized (122); and vi) separating the reduced zinc (104) from the industry product (110) using the non-oxidizing gas (130).

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SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, 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, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

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

A method for separating zinc from an industry product using a pyrometallurgical reaction

Field of the Invention

The invention relates to a method of separating (reduced) zinc from an oxidized zinc-containing industry product, in particular by using a pyrometallurgical reaction. The invention further relates to a use of said pyrometallurgical reaction for separating a metal alloy from the oxidized zinc-containing industry product. The invention can therefore relate to the technical field of metallurgy, in particular to the chemical separation of zinc from a metal (oxide)- and/or valuable element-rich industry product.

Technological Background

Industry products may contain a high amount of (oxidized) metals and/or valuable elements, for example (oxidized) zinc. These industry products may be byproducts and/or waste of industry processes like a metal, in particular steel, zinc, lead or copper, production process. Due to the content of economically relevant elements such as zinc, the described industry products may be considered as a high-potential source of raw material (resource). However, the metals in said industry products are mostly oxidized (in form of many different mineral compounds like zinc ores, e.g. zinc oxide or zinc ferrite), so that separating the valuable elements out of the industry products in a reduced (metallic) state may be considered as effort-intensive and environmentally harmful.

Conventionally, industry products with a high content of oxidized metals and a low content of non-oxidized metals (e.g. electric arc furnace (EAF) dust) are treated in a rotation process. Hereby, the industry product is mixed with carbon (150-200 kg carbon per ton of industry product) in a rotary tube, wherein a carbothermal reduction treatment is carried out at temperatures of about 1200-1300°C. This treatment leads to a reduction of the oxidized zinc, wherein reduced (in particular metallic) zinc is obtained (due to the high temperature) in the gaseous state. An inevitable disadvantage of this method is, however, that the reduced zinc is oxidized again to zinc oxide particles. This happens because the reaction atmosphere (oxygen or oxygen-containing air or gas) is necessarily oxidizing (not inert) in order to enable the formation of carbon dioxide. In the end, the zinc is separated from the industry product, but is again in the oxidized state (so-called "crude zinc oxide", ZnO) and has to be further treated in a costly manner. When using this technology, the recovery for zinc is usually about 85-90%. In addition, about 700 kg of slag remains per ton of input material, which in most cases ends up in a landfill (e.g. 200 kg of carbon may result in more than 700 kg of produced CO_2). Low and medium zinc content industry products cannot be economically processed by the described conventional method.

Summary of the Invention

It is an object of the invention to provide a method of separating zinc from an oxidized zinc-containing industry product (after reducing at least parts of the oxidized zinc to metallic zinc) in an efficient and environmentally friendly manner.

The object defined above may be solved by the subject matters described by the independent claims. The dependent claims describe preferred embodiments.

According to an exemplary embodiment of the invention, it is described a method for separating (reduced, metallic) zinc from an industry product (e.g. EAF dust), the method comprising:
i) providing the industry product, which comprises oxidized zinc (to a heating device (e.g. a furnace)),
ii) heating the industry product (e.g. in the temperature range 1300°-1500°C) (by the heating device) so that the industry product (at least partially) melts (e.g. forms a slag),
iii) providing a reduced (non-zinc) metal (e.g. reduced iron in an iron waste (scrap) product or an oxidized non-zinc metal from the industry product which is then selectively reduced beforehand) (in the heating device) to the (or as part of the) industry product, thereby forming an interface (region) between the at least partially melted industry product and the reduced metal,

iv) providing (streaming) a non-oxidizing gas (in particular an inert gas such as nitrogen) (into the heating device and) to (between) the (metal-slag) interface,
v) performing a chemical reaction (in particular a pyrometallurgical reaction, in other words a metallothermic reduction) at the interface (region) between the (at least partially) melted industry product and the reduced (non-zinc) metal in the presence of the non-oxidizing gas, so that the oxidized zinc is reduced and the (non-zinc) reduced metal is oxidized, and
vi) separating (removing) the reduced zinc (in particular in the gaseous state) from the heating device (in particular using the non-oxidizing gas (more in particular wherein the gaseous zinc is mixed with the non-oxidizing gas)).

According to a further aspect of the invention, it is described a use of a pyrometallurgical reaction (as described above) at an interface between an at least partially melted oxidized metal (e.g. zinc) comprising industry product and a reduced (non-zinc) metal in the presence of an non-oxidizing gas for separating a metal alloy from the industry product, wherein the metal alloy comprises at least one metal (e.g. cobalt, nickel, copper) that is more noble than the reduced metal (in particular wherein the reduced metal comprises iron and/or has a low vapor pressure at process temperature to prevent its evaporation, more in particular comprises a lower vapor pressure than zinc).

In the context of this document, the term "chemical reaction" may in particular refer to a pyrometallurgical treatment, in particular a metallothermic melt reduction. For providing a better understanding of said term, an exemplary embodiment is discussed in the following. The industry product, which may e.g. comprise iron- and zinc-oxide-containing residues, is heated to the extent that it melts (e.g. larger than 1350 °C) and forms a liquid slag phase. In the presence of a reduced (non-zinc) metal, such as metallic iron, the zinc oxide dissolved in the liquid slag phase reacts to gaseous reduced zinc, while the metallic iron reacts to iron oxide according to the following equations (s=solid, l=liquid, g=gaseous):

$$ZnO\ (l) + Fe(l) \rightarrow Zn(g) + FeO(l), \text{ and/or}$$

$$ZnO(l) + Fe(s) \rightarrow Zn(g) + FeO(l).$$

It may be considered crucial to introduce a non-oxidizing gas in order to start the reaction and control the kinetics.

In the equation above, the example of zinc oxide is shown. It is, however, clear that an equivalent chemical reaction (reduction) may also take place for other chemical compounds, in which zinc is oxidized (there are more than 300 zinc minerals/ores known). These zinc compounds may include for example: ZnS, $ZnCO_3$, $Zn_2(SiO_4)$.

At the interface between the (industry product) liquid slag phase and the reduced metal phase, the reduced gaseous zinc is formed, which is mixed with the non-oxidizing carrier gas, and leaves the melting region (of the heating device) together with the non-oxidizing carrier gas. Outside of the heating zone of the heating device, the reduced, gaseous zinc may be condensed by cooling in the form of metallic zinc (solid or liquid). Hereby, due to the absence of an oxidizing atmosphere (would occure due to the formation of CO_2 by carbothermic reduction) a re-oxidation of the reduced zinc to zinc oxide is excluded.

In the context of this document, the term "industry product" may refer to any industry product that comprises oxidized zinc. The industry product may be a waste product and/or may comprise further (oxidized) elements such as iron. In an example, the industry product is a waste product from a steelmaking or copper making process. In particular, the industry product may be present as (dust) particles, for example EAF dust. Table 1 below shows an example of the content (in weight percent) of an oxidized zinc-containing industry product.

Table 1

Zinc content	Fe	Zn	Ca	Na	Pb	Si	K	Mn	Cu	Cl
Low	48.6	3.8	3.8	0.6	1.0	1.9	0.7	5.8	0.2	1.4
Medium	41.1	8.1	4.1	0.6	2.1	1.9	0.8	5.2	0.3	1.9
High	29.0	27.0	3.1	1.5	2.5	1.3	1.2	2.3	0.3	3.6

According to an exemplary embodiment, the invention may be based on the idea that a method of separating zinc from an oxidized zinc-containing industry product after the reduction of the oxidized zinc can be performed in an efficient and environmentally friendly manner, when a pyrometallurgical reaction is performed at an interface between the (partially) melted industry product and a reduced metal in the presence of a non-oxidizing gas.

Basically, the redox reaction between oxidized zinc and a reduced metal (in particular iron) is kinetically inhibited. However, it has been most surprisingly found by the inventors that this reaction can be enabled and the kinetic inhibition can be released by inserting a non-oxidizing gas at the interface (the phase boundary surfaces) of the (partially) melted industry product and the (liquid or solid) reduced metal.

The inventors found that without the presence of the non-oxidizing gas (e.g. nitrogen) at the interface, the reaction between zinc oxide and reduced metal does not take place. Therefore, the non-oxidizing gas may have to be provided in order to start the reaction and control its kinetics.

The described method does not require any carbon and applies instead a reduced metal such as iron as a reducing agent for the zinc oxide. The reduced metal can be provided in a cost-efficient and environmentally friendly manner, for example as a metal-rich waste product (e.g. a low-quality steel scrap). In the usual case that the industry product contains oxidized metal, in particular iron oxide, a reduction step can be performed in order to selectively reduce the contained metal to directly provide the reduced metal.

In contrast to the carbothermic reduction of the prior art, the metallothermic reaction does not result in CO_2 production (the net reaction, evaporation and condensation of zinc does not result in gas development), which allows the process to operate in an inert atmosphere or vacuum. This makes it possible to prevent the re-oxidation of the reduced zinc. In this manner, metallic zinc can be directly obtained, which significantly improves the (zinc) product (e.g. prime western grade zinc) quality and increases revenues.

The chemical reactions take place between liquid/liquid or liquid/solid phases, which results in much higher reaction kinetics compared to the slower solid-gas-solid reactions of the prior art. Further, this leads to a significant reduction in the required size of the industrial facility. While conventionally a landfill-required slag fraction was produced during the process, now a (valuable) element (e.g. iron) oxide-rich fraction is produced, which can be provided/sold to the iron and steel industry as a second product beyond the zinc.

In an exemplary embodiment, a zinc oxide concentration of less than 1% has been achieved in the depleted industry product, while the iron oxide concentration was around 80% in said product.

The discovery of the above described process leads further to the surprising finding, that another side-product of said process is a metal alloy that comprises metals which are more noble than the reduced metal (and comprise a lower vapour pressure than zinc). While the reduced industry product (in particular iron scrap) may be considered as a low-quality scrap with respect to noble metals (in particular copper), said metals may be highly enriched in the metal alloy, resulting in an interesting product for commercial exploitation.

According to an embodiment, the reduced zinc is in gaseous state and is at least partially mixed with the non-oxidizing gas. This may provide the advantage that the reduced zinc is efficiently removed from the industry product (melt). The melting point of zinc is much lower than that of zinc oxide, hence the reduced zinc is in gaseous state under the heated reaction conditions. The zinc gas is mixed with the non-oxidizing gas at the interface and transported away from the industry product (melt).

According to a further embodiment, the chemical reaction is a pyrometallurgical reaction that is performed in non-oxidizing conditions (non-oxidizing atmosphere, inert atmosphere, vacuum), in particular (essentially) in the absence of oxygen and carbon dioxide. This may provide the advantage that the reduced zinc is efficiently separated from the industry product without being re-oxidized again. Since (essentially) no carbon dioxide is generated (some carbon dioxide may be generated due to minimal carbon contents in the industrial waste and/or scrap fraction), the reaction atmosphere can be inert (non-oxidizing).

The industry product starting material may contain minor concentrations of water and carbon (e.g. below 1%). Therefore, CO, CO_2, H_2O, and H_2 may be present at the beginning of performing the method. These gases may be removed in order to provide the non-oxidizing reaction conditions. For example, the undesired gases may be streamed through a gas outlet.

According to a further embodiment, the reduced metal is a non-zinc metal, in particular the reduced metal comprises (consists of) iron. This may provide the advantage that the reduced metal can be provided in a very cost-efficient manner, e.g. as a low quality scrap fraction (in particular steel scrap with a high copper concentration). In principle each metal could be applied with which the described metallothermic reaction is possible, for example also aluminum or silicon.

In the context of this document, the term "non-zinc" refers to the circumstance that a product comprises (essentially) no zinc or is depleted of zinc. This may not mean that the product is completely zinc-free. Instead, the term "non-zinc" may include small amounts, residues or traces. For example, a low zinc content EAF dust is not described as a non-zinc product in this context. A metal-rich waste product that is described as non-zinc in this context, may only comprise zinc in small (not essential) amounts (for example, the scrap material may have a zinc coating).

According to a further embodiment, the reduced (non-zinc) metal is present during the chemical reaction as at least one of the group which consists of liquid state, solid state, dissolved in a solid alloy or in a liquid alloy. This may provide the advantage that the chemical reaction can be performed in a very flexible manner in different states of the reduced metal (product). In a preferred embodiment, the reduced (non-zinc) metal may be (at least partially) melted and hence be present in the liquid form. In another embodiment, the reduced (non-zinc) metal (mixture) may be partially melted with solid iron particles floating on the surface. In case that the reduced (non-zinc) metal is surrounded by one or more other metals, the reduced metal may be provided as an alloy.

According to a further embodiment, the non-oxidizing gas is an inert gas, in particular at least one of nitrogen and a noble gas. This may provide the advantage that a non-oxidizing and inert atmosphere is provided, while at the same time, the reduced zinc can be separated and transported away from the industry product in an efficient manner. In principle, each non-oxidizing gas or mixture of non-oxidizing gases may be applied, whereby an inert gas is preferred. Hence, a cost-efficient gas such as nitrogen may be considered as an economical first choice.

According to a further embodiment, the non-oxidizing gas is selectively provided (streamed) to the interface. This may provide the advantage that the reaction is performed especially efficient. The non-oxidizing gas may be provided as a carrier or rinsing gas. For example, the gas may be introduced with a lance from the top of the heating device. In another example, the gas may be introduced from the bottom of the heating device through flushing stones installed in the heating device, e.g. furnace, from below. Hereby, the gas flow rate of the non-oxidizing gas may control the kinetics of the chemical reaction (metallothermic reduction).

According to a further embodiment, the reduced metal is provided as an additional material to the chemical reaction, in particular as part of an industry waste product, more in particular an iron-rich waste product (e.g. steel scrap). This may provide the advantage that the reduced metal is provided directly in a cost-efficient manner, since a recyclable/waste product can be directly applied. In principle, a wide variety of additional products are possible, as long as at least one metal in the additional product is essentially present in a reduced form to enable the described reaction with the oxidized zinc within the treated industry product.

According to a further embodiment, the industry product comprises an oxidized non-zinc metal, and wherein providing the reduced non-zinc metal comprises: selectively reducing (e.g. in an additional reduction device) the oxidized non-zinc metal in order to obtain the reduced metal, in particular using a reducing gas, more in particular at least one of carbon monoxide and hydrogen. This may provide the advantage that no additional step of providing a reduced metal product (e.g. steel scrap) is necessary, and the industry product serves at the same time as a source of zinc and as a reducing agent. Hereby, less material has to be heated and the energy consumption is lower. Metal, such as iron, is essentially oxidized (e.g. iron oxide) in the industry product. A selective reduction step is performed in a preferred embodiment. In an example, a reducing atmosphere is provided (e.g. H_2 or CO at 500-700°C for 1-3 hours). The reaction may take place in a vertically oriented device (e.g. retort) or similar to midrex. The selective gas reduction lowers the energy necessary to perform the melting step, because less material must be heated (in particular less or no addition of scrap is required).

According to a further embodiment, the temperature during the melting and/or during the chemical reaction is at least temporally in the range of 1350° to 1500°C. Said temperature range has been found as being very efficient in order to achieve the desired chemical reaction while saving energy.

According to a further embodiment, the industry product comprises dust particles, in particular zinc-containing dust from the steel, copper, zinc, or lead making industry. In this manner, a mass waste product of an important industry can be directly applied as an interesting resource of zinc. With the described method, even industry products with low- or medium-zinc contents (see Table 1 above) can be efficiently recycled with respect to zinc recovery.

According to a further embodiment, the method further comprises agglomerating of the dust particles. The dust particles may be e.g. agglomerated to pellets or pressed to briquettes. This pellets or briquettes can be used in a flexible manner to adopt necessary amounts easily.

According to a further embodiment, the method further comprises condensing the reduced gaseous zinc in order to obtain metallic zinc in solid state or liquid state. This may provide that the industrially relevant metallic zinc can be directly obtained without a re-oxidation in between.

According to a further embodiment, the method further comprises: separating and condensing at least one further metal (having a high vapour pressure like zinc, in particular lead) from the industry product using the non-oxidizing gas. Additionally or alternatively, the method further comprises: separating and condensing at least one alkali-metal (in particular K or Na) and at least one halogen (in particular Cl or F) in the form of a halide from the industry product using the non-oxidizing gas.

Substances contained in the industry product (e.g. K-, Na-, Cl-, F-, Pb-compounds) may also evaporate (mixed with the non-oxidizing gas) and accumulate together with the zinc in the condenser. While further metals, such as lead, dissolve (during condensation) into the zinc (to form a zinc metal alloy), halogens such as chlorides and fluorides form a salt slag.

According to a further embodiment, a salt slag is formed that includes the at least one alkali-metal and/or the at least one halogen, wherein the reduced zinc (or the zinc metal alloy) is at least partially mixed with the salt slag, and wherein the method further comprises: separating the reduced zinc (or zinc metal alloy) from the salt slag, in particular using a separation (in liquid state) based on density. In this manner, the zinc (metal alloy) can be separated from the salt slag using known and established methodologies.

According to a further embodiment, a zinc metal alloy is formed that includes at least one further metal (in particular lead) and the reduced zinc, and wherein the method further comprises: separating the reduced zinc from the zinc metal alloy using at least one of the group which consists of separation by liquidation (segregation), distillation or electrolysis. In this manner, the zinc can be separated from the further metal(s) using known and established methodologies. Zinc alloy can be refined by known methods and may be marketed as zinc grade Z5 or PWG-R (classification according to DIN EN 1179 or ASTM B 960-08) in the form of ingots.

According to a further embodiment, the heating and/or the chemical reaction is performed in a heating device, wherein the heating device comprises at least one of the group which consists of an induction furnace, a resistance heated furnace, an electric arc furnace. Said heating devices have been found as especially suitable for performing the described heating and pyrometallurgical reaction. The heating device comprises a cavity into which the industry product is brought, e.g. in form of dust particles through an aperture. The heating device may further comprise an inlet for the non-oxidizing gas, so that said gas is enabled to stream to the interface. Further, the heating device may comprise an outlet (in particular to a condenser) through which the mixture of non-oxidizing gas and the gaseous zinc can leave the heating device.

According to a further embodiment, the method further comprises: separating a (non-zinc) metal alloy from the industry product. In particular, the metal alloy comprises at least one (noble) metal that comprises a higher redox potential than the reduced metal (e.g. iron). It has been surprisingly found that the described chemical reaction further produces a metal alloy of metal being more noble than the reduced metal. This may provide the advantage that industry-relevant resources can be obtain in a very cost-efficient manner as a by-product.

In the context of this document, the term "noble" (metal) can be understood in particular as follows: if the standard potential (redox potential, or according to DIN 38404-6 "redox voltage") of a first metal is higher than the standard potential of a second metal, then the first metal is more noble in relation to the second metal and the second metal is less noble than the first metal.

Metals with a high redox potential (more noble metals) may include, for example: copper Cu^{2+}, E^0 = +0,35V; copper Cu^{+}, E^0 = +0,52V, palladium Pd^{2+}, E^0 = +0,85V; gold Au^{3+}, E^0 = +1,4V; gold Au^{2+}, E^0 = +1,5V; gold Au^{+}, E^0 = +1,69V;iridium Ir^{3+},E^0 = +1,156V; silver Ag^{+}, E^0 = +0,8V.

Metals with low redox potential (less noble metals) may include, for example: iron Fe^{3+}, E^0 = -0,04V; iron Fe^{2+}, E^0 = -0,41V; lead Pb^{2+}, E^0 = -0,13V; tin Sn^{2+}, E^0 = -0,14V; nickel Ni^{2+}, E^0 = -0,23V; cobalt Co^{2+}, E^0 = -0,28V; indium In^{3+}, E^0 = -0,34V; cadmium Cd^{2+}, E^0 = -0,40V; zinc Zn^{2+}, E^0 = -0,76V; chromium Cr^{3+}, E^0 = -0,76V; sodium Na^{+}, E^0 = -2,71V.

In an example, the noble metal comprises a vapour pressure that is (significantly) lower than the vapour pressure of zinc. The noble metal(s) remain(s) in the melt and become enriched (thereby forming the metal alloy), while the reduced metal becomes oxidized (thereby forming the metal oxide fraction).

Besides obtaining the valuable metal alloy, the described procedure may provide the advantage that the process temperature can be lowered (colligative melting point lowering). In this manner, energy can be saved, while the lifetime of fire-proofed (furnace) materials is prolonged. The metal alloy may be present in liquid state, while solid parts of reduced metal (iron) flow at the interface.

The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited.

Brief Description of the Figures

Figure 1 illustrates a method of separating zinc from an industry product according to an exemplary embodiment of the invention.

Figure 2 illustrates an industrial facility for performing the method of separating zinc from an industry product according to an exemplary embodiment of the invention.

Figure 3 illustrates a pyrometallurgical reaction at an interface between two liquid phases according to an exemplary embodiment of the invention.

Figure 4 illustrates a pyrometallurgical reaction at an interface between a liquid phase and a solid phase according to an exemplary embodiment of the invention.

Detailed Description of Exemplary Embodiments

According to an exemplary embodiment, the described method comprises: i) melting (to a slag) and treating of iron- and zinc-containing materials in an induction furnace in a temperature range between 1350 and 1500°C under inert gas atmosphere or vacuum, ii) using iron as a reducing agent, and iii) inserting a rinsing gas to the interface between metal and slag to enable and accelerate the reaction.

In the following, an exemplary example of the method is described. As a first process step, the iron- and zinc-containing residue (industry product), which is usually present as dust or sludge, is agglomerated and dried.
In variant 1, the dried and agglomerated dust is melted together with ferrous scrap (reduced metal) in an inert atmosphere. This leads to selective evaporation of reduced zinc.
In variant 2, the dried and agglomerated dust is treated in a metallurgical aggregate (for example a retort or a midrex (similar but lower temperature)) by reducing gases (for example CO, H_2) at 500-700°C for a duration of 1-4 hours. This leads to the selective reduction of the oxidic iron compounds contained in the dust to fine-dispersed metallic iron particles. The material thus pretreated is then melted in an inert atmosphere, as in variant 1. Depending on the dust composition, it may be necessary to add (ferrous) scrap for a high yield.

The reduced metal reacts with the oxidic zinc resulting in its selective evaporation. The liquid slag phase is tapped out of the furnace (heating device) after 1-3 hours, but at least as soon as the zinc oxide concentration is below a predefined threshold. The metal melt is tapped out of the furnace at long intervals, only to an extent to ensure a sufficient furnace volume for the slag phase. From a process-technical point of view, it is advantageous to keep a liquid metal sump in the induction furnace.

The illustrations in the drawings are schematically. It is noted that in different figures, similar or identical elements or features are provided with the same reference signs. In order to avoid unnecessary repetitions elements or features which have already been elucidated with respect to a previously described embodiment are not elucidated again at a later position of the description.

Further, spatially relative terms, such as "front" and "back", "above" and "below", "left" and "right", et cetera are used to describe an element's relationship to another element(s) as illustrated in the figures. Thus, the spatially relative terms may apply to orientations in use which differ from the orientation depicted in the figures. Obviously, though, all such spatially relative terms refer to the orientation shown in the figures for ease of description and are not necessarily limiting as an apparatus according to an embodiment of the invention can assume orientations different than those illustrated in the figures when in use.

Figure 1 shows a method of separating zinc from an industry product 110 according to an exemplary embodiment of the invention. The industry product 110 is a valuable element and (oxidized) metal-rich product that comprises oxidized zinc and other (oxidized) metals such as iron and copper. For example, the industry product 110 is a waste product from a steel, copper, lead, or zinc making process (e.g. electric arc furnace (EAF) dust) and is present in the form of dust particles. Optionally, the dust particles are agglomerated to pellets or briquettes in an additional step. The industry product 110 is provided into a heating device 150, preferably an induction furnace. In a further step, a non-zinc reduced metal 120 is provided within the heating device 150.

In the Figure, two variants V1, V2 for providing the non-zinc reduced metal 120 are shown, which methods can be applied in combination or alternatively. In the first variant V1, the non-zinc reduced metal 120 is provided as part of an industry waste product 120a, wherein the industry waste product 120a is for example a metal scrap fraction, e.g. a steel scrap fraction. According to the second variant V2, the industry product 110 contains non-zinc oxidized metal (in particular oxidized iron) 120b and said oxidized metal 120b is selectively reduced in a reduction device 140 in order to provide the reduced non-zinc metal 120. The reduction is performed using a reducing gas, for example carbon monoxide and/or hydrogen.

The industry product 110 is at least partially melted in the heating device 150 and a non-oxidizing gas 130 such as nitrogen is selectively provided to an interface between the industry product 110 and the reduced metal 120. The chemical (pyrometallurgical) reaction is performed in the heating device 150 at said interface 115 between the at least partially melted industry product 111 and the reduced metal 120 in presence of the non-oxidizing gas 130, so that the oxidized zinc 102 is reduced 104 and the reduced metal 120 is oxidized 122, 163 (not shown in Figure 1). This reaction leads to a separation of the reduced zinc 104 in gaseous state from the industry product 110 by using (i.e. in a mixture with) the non-oxidizing gas 130.

The described method yields in principle the product fractions: i) the reduced zinc 104 (this fraction may also contain further metals, e.g. as a zinc metal alloy, such as Pb), ii) a salt slag 161, iii) a (noble) metal alloy 162, and iv) the oxidized non-zinc metal fraction 163. The salt slag 161 is mainly formed by alkalimetals (e.g. Na, K) and halogens (e.g. Cl, F) that evaporate from the industry product 110 together with the reduced zinc 104. The metal alloy 162 is formed by (reduced) metals from the industry product 110, which are more noble than the reduced metal, but comprise a (significantly) lower vapour pressure than zinc (e.g. copper, nickel, cobalt, etc.).

Figure 2 illustrates an industrial facility 100 for performing the method of separating zinc from an industry product 110 according to an exemplary embodiment of the invention. The industrial facility 100 comprises a heating device 150 realized as an induction furnace comprising a wall structure 153 around a heating cavity, induction coils 152, and an inlet 151 for streaming a non-oxidizing gas 130 into the heating device 150.

In a first step, the industry product 110 (in the example shown as an EAF dust) is provided as (agglomerated) dust particles through an aperture into the heating device 150. Further, a reduced metal (iron)-rich waste product 120 is provided at the bottom of the heating device 150. The industry product 110 particles are hereby provided on top of the reduced metal 120, whereby an interface 115 region is obtained. The heating device 150 is configured for heating to a temperature in the range 1350° to 1500° C, so that the industry product 110 at least partially melts and forms an oxidized metal (in particular zinc) melt 111. The reduced metal 120 fraction is also at least partially melted to a metal (reduced iron) melt in the example shown. The non-oxidizing gas 130 (in the example shown nitrogen is used) is selectively streamed to the interface 115 between the oxidized metal (zinc) melt 111 and the reduced metal (iron) melt

120. The cavity of the heating device 150 is free of oxidizing gases. Due to the described conditions, a pyrometallurgical reaction takes place at the interface 115, so that the oxidized zinc 102 is reduced and the reduced metal (iron) 120 is oxidized. In this manner, the reduced zinc 104 is separated from the oxidized metal (zinc) melt 111 in gaseous state, being in a mixture with the non-oxidizing gas 130.

Said gas mixture 104, 130 streams out of the heating device 150 into a condenser device 180 of the industrial facility 100. Herein, the reduced zinc 104 is condensed to metallic (liquid or solid) zinc 106. Further, (at least part of) the salt slag 161 and a zinc metal alloy 164 (that may contain e.g. lead) is also condensed. Hereby, the reduced zinc 104 can be (at least partially) present within the zinc metal alloy 164.

The non-oxidizing gas 130 is then streamed to a so-called bag house device 181, wherein fines and dust particles are separated. Afterwards, the washed (refined) non-oxidizing gas 130 is again provided (recycled) through the inlet 151 into the heating device 150. In this manner, the non-oxidizing gas 130 can be maintained in the production cycle which saves resources.

The industry product 110 starting material may contain minor concentrations of water and carbon. Therefore, CO, CO_2, H_2O, and H_2 may be present in the heating device 150. These gases should be removed in order to provide non-oxidizing reaction conditions. Said undesired gases are therefore streamed through a gas outlet 182 out of the industrial facility 100. The step of removing the undesired gases should be done at the beginning of each cycle (batch).

Figure 3 illustrates in detail the pyrometallurgic reaction described for Figure 2 above. It shows the interface 115 between the reduced metal (iron) melt 120 (the reduced metal is at least partially liquid) and the oxidized metal (zinc) melt 111 (industry product 110 at least partially melted). The non-oxidizing nitrogen gas 130 is selectively streamed to the interface 115 between the oxidized zinc melt 111 and the reduced iron melt 120. At the interface 115, the oxidized zinc 102 is reduced and the reduced iron 120 is oxidized. In this manner, the reduced zinc 104 is separated from the oxidized zinc melt 111 in gaseous state, mixed with the non-oxidizing gas 130.

Figure 4 illustrates in detail an alternative embodiment of the pyrometallurgical reaction described for Figure 3 above. In this example, the reduced iron 120 is (at least partially) solid. For example, solid iron particles may float on an (at least partially) melted reduced metal melt 120. The described pyrometallurgical reaction takes place at such a solid iron particle.

It should be noted that the term "comprising" does not exclude other elements or steps and the use of articles "a" or "an" does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

It is noted that it may also be possible in further refinements of the invention to combine features from different illustrative embodiments described herein. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

Reference signs

100	industrial facility
102	oxidized zinc (ZnO)
104	reduced zinc (Zn)
106	metallic zinc
110	industry product
111	at least partially melted industry product
115	interface
120	reduced (non-zinc) metal
120a	industry waste product (iron/steel scrap fraction)
120b	oxidized non-zinc metal in industry product
122	oxidized non-zinc metal
130	non-oxidizing gas
140	reduction device
150	heating device
151	(recycled) gas inlet
152	induction coils
153	wall structure
161	salt slag
162	metal alloy
163	oxidized non-zinc metal fraction
164	zinc metal alloy
180	condenser
181	bag house
182	(undesired) gas outlet
183	fines, dust particles

Claims

1. A method for separating zinc from an industry product (110), the method comprising:

providing the industry product (110) which comprises oxidized zinc (102);

heating the industry product (110) so that the industry product (110) at least partially melts (111);

providing a reduced metal (120) to the industry product (110), thereby forming an interface (115) between the at least partially melted industry product (111) and the reduced metal (120);

providing a non-oxidizing gas (130) to the interface (115);

performing a chemical reaction at the interface (115) between the at least partially melted industry product (111) and the reduced metal (120) in the presence of the non-oxidizing gas (130), so that the oxidized zinc (102) is reduced (104) and the reduced metal (120) is oxidized (122); and

separating the reduced zinc (104) from the industry product (110).

2. The method according to claim 1, wherein the reduced zinc (104) is in gaseous state and is at least partially mixed with the non-oxidizing gas (130).

3. The method according to claim 1 or 2, wherein the chemical reaction is a pyrometallurgical reaction that is performed in non-oxidizing conditions, in particular essentially in the absence of oxygen and/or carbon dioxide.

4. The method according to any one of the preceding claims, wherein the reduced metal (120) is a non-zinc metal, in particular wherein the reduced metal (120) comprises iron.

5. The method according to any one of the preceding claims, wherein the reduced metal (120) is present during the chemical reaction as at least one of the group which consists of liquid state, solid state, dissolved in a solid alloy or in a liquid alloy.

6. The method according to any one of the preceding claims,
wherein the non-oxidizing gas (130) is an inert gas, in particular at least one of nitrogen and a noble gas.

7. The method according to any one of the preceding claims,
wherein the non-oxidizing gas (130) is selectively provided to the interface (115).

8. The method according to any one of the preceding claims,
wherein the reduced metal (120) is provided as an additional material (120a) to the chemical reaction,
in particular the reduced metal (120) is part of an industry waste product (120a), more in particular of a metal scrap fraction.

9. The method according to any one of the preceding claims,
wherein the industry product (120b) comprises an oxidized non-zinc metal (122), and wherein providing the reduced metal (120) comprises:
selectively reducing the oxidized non-zinc metal (122) in order to obtain the reduced metal (120),
in particular using a reducing gas, more in particular at least one of carbon monoxide and hydrogen.

10. The method according to any one of the preceding claims,
wherein the temperature during the melting and/or during the chemical reaction is at least temporally in the range 1350° to 1500°C.

11. The method according to any one of the preceding claims,
wherein the industry product (110) comprises zinc-containing dust particles,
in particular dust particles from the steel, copper, lead, or zinc making industry.

12. The method according to claim 11,
wherein the method further comprises agglomerating the dust particles.

13. The method according to any one of the preceding claims, wherein the method further comprises:

condensing (180) the reduced gaseous zinc (104) in order to obtain a metallic zinc (106) in solid state or liquid state.

14. The method according to claim 13,
wherein the method further comprises:

separating and condensing at least one further metal, in particular Pb, from the industry product (110) using the non-oxidizing gas (130); and/or

separating and condensing at least one alkali-metal, in particular K or Na, and at least one halogen, in particular Cl or F, in the form of a halide from the industry product (110) using the non-oxidizing gas (130).

15. The method according to claim 14, wherein a salt slag (161) is formed that includes the at least one alkali-metal and the at least one halogen, wherein the reduced zinc (104) is at least partially mixed with the salt slag (161), and wherein the method further comprises:

separating the reduced zinc (104) from the salt slag (161),
in particular using a liquid separation based on density.

16. The method according to claim 14 or 15,
wherein a zinc metal alloy (164) is formed that includes the at least one further metal and the reduced zinc (104), and wherein the method further comprises:

separating the reduced zinc (104) from the zinc metal alloy (164) using at least one of the group which consists of a separation by liquidation, a distillation, an electrolysis.

17. The method according to any one of the preceding claims,
wherein the heating and/or the chemical reaction is performed in a heating device (150), in particular wherein the heating device (150) is one of the group which consists of an induction furnace, a resistance heating furnace, an electric arc furnace.

18. The method according to any one of the preceding claims, wherein the method further comprises:

separating a metal alloy (162) from the industry product (110), in particular wherein the metal alloy (162) comprises a noble metal that is more noble than the reduced metal (120).

19. Using a pyrometallurgical reaction at an interface (115) between an at least partially melted oxidized metal comprising industry product (111) and a reduced metal (120) in the presence of a non-oxidizing gas (130) for separating a metal alloy (162) from the industry product (110), wherein the metal alloy (162) comprises at least one metal that is more noble than the reduced metal (102).

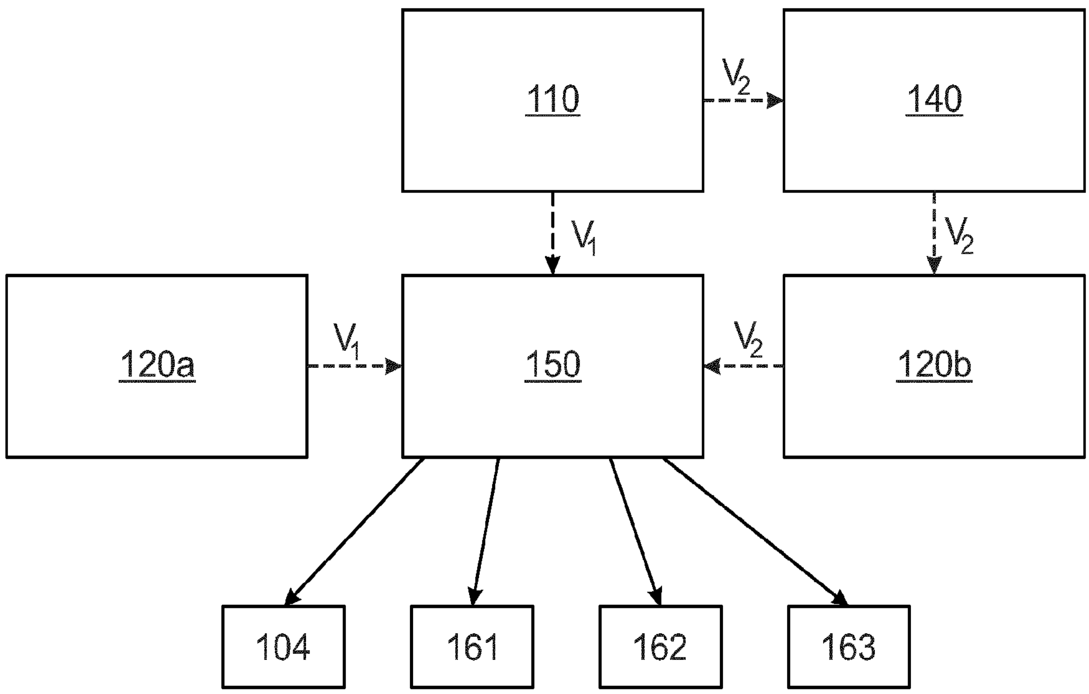

Fig. 1

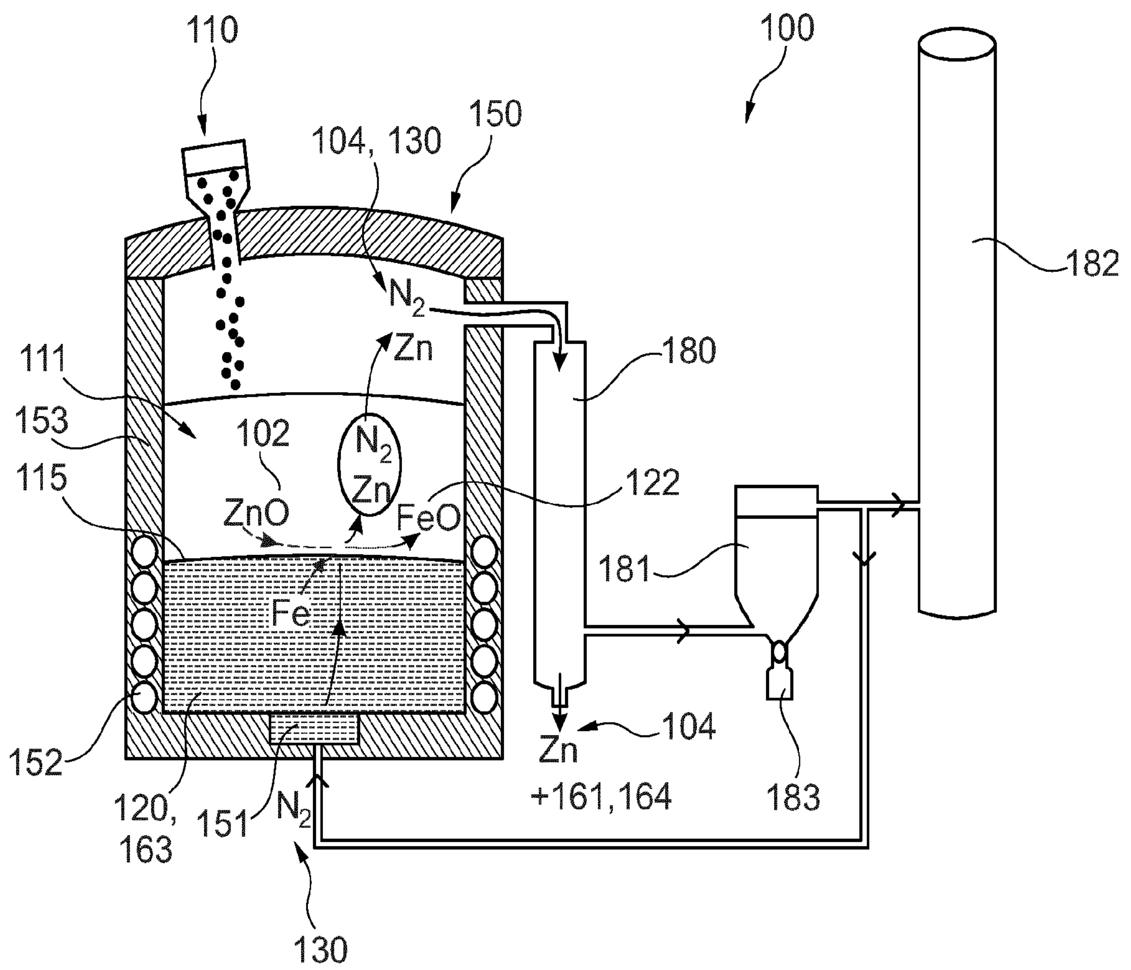

Fig. 2

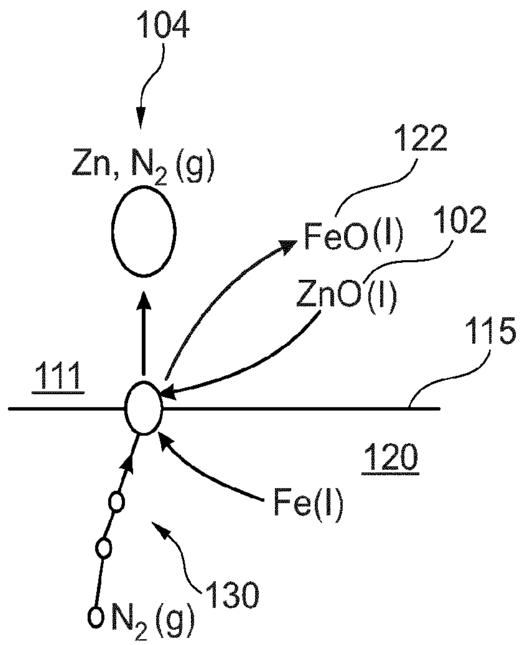

Fig. 3

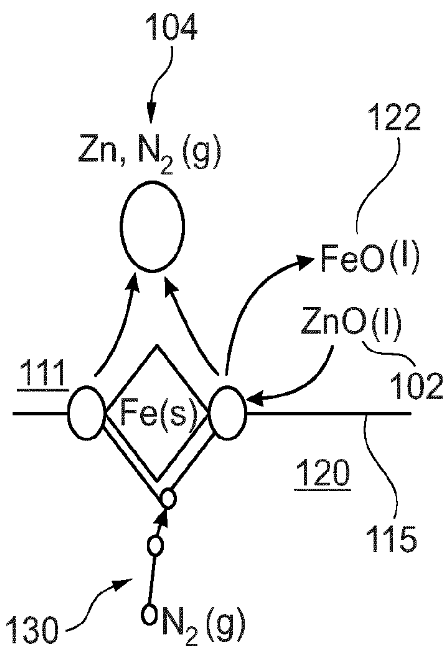

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/073313

A. CLASSIFICATION OF SUBJECT MATTER
INV. C22B5/12 C22B7/02 C22B7/04 C22B13/02 C22B19/16
C22B19/18 C22B19/30
ADD.

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)
C22B

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 372 780 A (MADELIN BERTRAND [FR]) 8 February 1983 (1983-02-08) figure 1 claims 1, 4, 6, 7, 13, 14, 23 example 1 column 1, line 7 - line 13 column 1, line 23 - line 56 column 3, line 56 - line 60 column 4, line 9 - line 26 column 4, line 54 - line 66 column 5, line 62 - line 63 -----	1-19

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

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search	Date of mailing of the international search report
16 March 2021	25/03/2021

Name and mailing address of the ISA/	Authorized officer
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Form PCT/ISA/210 (second sheet) (April 2005)

International application No
PCT/EP2020/073313

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