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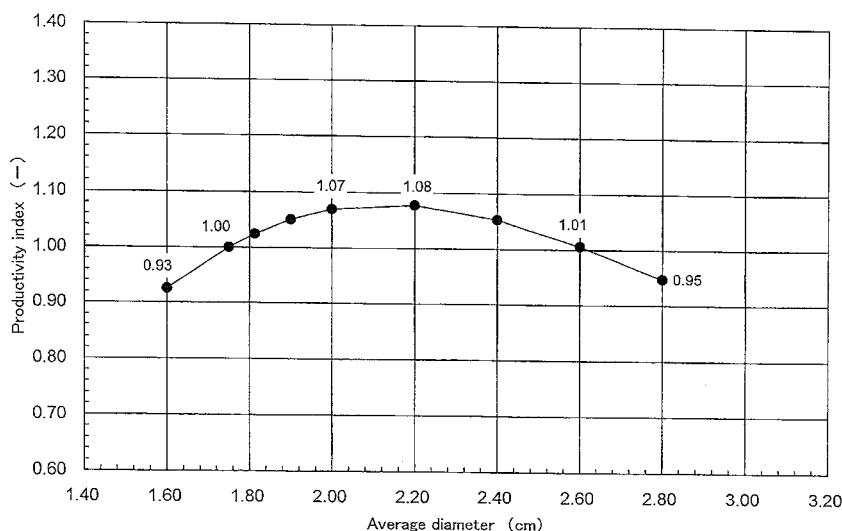
(54) **GRANULAR METAL PRODUCTION METHOD**

(57) The present invention is to provide a technique that further improves the process for producing granular metal by heating agglomerates containing a metal oxide and a carbonaceous reducing agent, and reducing and melting the metal oxide included in the agglomerates.

The process for producing granular metal comprising the steps of: feeding agglomerates containing a metal oxide and a carbonaceous reducing agent onto a hearth

of a moving hearth-type reduction melting furnace; heating the agglomerates to reduce and to melt the metal oxide; cooling the granular metal obtained by said heating step; and discharging the cooled granular metal out of the furnace to recover the same, wherein the agglomerates having an average diameter of not smaller than 17.5 mm are fed onto the hearth when the agglomerates are heated at a spread density of not lower than 0.5 on the hearth.

FIG. 6



Description

TECHNICAL FIELD

[0001] The present invention relates to a process for producing granular metal by feeding agglomerates configured by a raw material mixture containing a metal oxide and a carbonaceous reducing agent onto a hearth, and by heating the same thereon to reduce and to melt the metal oxide in the raw material mixture.

[0002] Mainly described herein is the process for producing granular metallic iron, in which the present invention is utilized most effectively. However, the present invention is not limited to the above but can be effectively utilized also to a case of heating and reducing chromium-containing ore or nickel-containing ore, for example, to produce ferrochromium, ferronickel, or the like. Moreover, the term "granular" in the present invention does not necessarily mean a perfectly spherical shape, but also includes elliptical and ovoidal shapes, as well as any shapes obtained by slightly flattening these shapes, and the like.

BACKGROUND ART

[0003] There has been developed a direct reduced iron manufacturing method for obtaining granular metallic iron from agglomerates configured by a raw material mixture including an iron oxide-containing material such as iron ore or iron oxide, and a carbonaceous reducing agent. In this iron producing process, the agglomerates are charged onto a hearth of a heating furnace and then heated in the furnace by the gas heat transfer with use of a heating burner or by radiation heat to reduce the iron contained in the agglomerates by the carbonaceous reducing agent. Subsequently, the reduced iron obtained by said heating step is carburized, melted, and then coalesced in the form of granules while being separated from sub-generated slag, and the granules are cooled and solidified to obtain granular metallic iron.

[0004] The above iron producing process does not require a large scale facility such as a blast furnace and has high flexibility with regard to resources, for example, because of no need to use coke, and therefore, in recent years, this process has widely been studied for practical use. However, this iron producing process still has many problems to be solved in order to be applied on an industrial scale, including the stability of operation, safety, economic efficiency, quality of the granular metallic iron (i.e., a final product), and productivity. In view of these problems, the applicant of the present invention previously proposed a method disclosed in Patent Document 1. In this method, upon heating and reducing formed products containing a carbonaceous reducing agent and iron oxide to produce metallic iron, suppressed as much as possible are the amount of the carbonaceous reducing agent consumed and the thermal energy necessary for the heating and reducing process so as to efficiently reduce the iron oxide at lower cost on a commercial scale. This document discloses an example in which iron ore, a carbonaceous material, and a binder are blended together to produce granular pellets having the average diameter of 17 mm, and the pellets are heated and reduced to produce metallic iron.

PRIOR ART DOCUMENT

PATENT DOCUMENT

[0005] Patent Document 1: Japanese Unexamined Patent Publication No. H11-241111

SUMMARY OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0006] According to above Patent Document 1, the carbonaceous reducing agent is blended at an amount in consideration of the stoichiometric amount required to the reduction of iron oxide and the solution C content into the metallic iron to be generated, and the heating temperature is appropriately controlled in consideration of the melting point of the metallic iron upon the solution of C. Thus, heating and reducing the iron oxide as well as the separation from slag by melting the iron oxide can be effectively progressed by using the carbonaceous reducing agent of the minimum amount required at the heating temperature as low as possible. As a result, there was established a process for producing metallic iron more economically and highly practically on an industrial scale. However, what is required is to further increase the amount of granular metallic iron produced per unit area of the effective hearth per unit time, in order to improve the productivity of the granular metallic iron.

[0007] The present invention was made in consideration of the above circumstances, and an object thereof is to provide a technique that further improves the process for producing granular metal by heating agglomerates containing a metal oxide and a carbonaceous reducing agent, and reducing and melting the metal oxide included in the agglomerates.

SOLUTIONS TO THE PROBLEMS

[0008] A process for producing granular metal, according to the present invention is characterized by comprising the steps of:

feeding agglomerates containing a metal oxide and a carbonaceous reducing agent onto a hearth of a moving hearth-type reduction melting furnace;
 heating the agglomerates to reduce and to melt the metal oxide;
 cooling the granular metal obtained by said heating step; and
 discharging the cooled granular metal out of the furnace to recover the same,
 wherein the agglomerates having an average diameter of not smaller than 17.5 mm are fed onto the hearth when the agglomerates are heated at a spread density of not lower than 0.5 on the hearth.

[0009] It is preferable that a carbonaceous material is spread on the hearth and then the agglomerates are fed on the carbonaceous material to form a single layer.

[0010] Iron oxide or steelmaking dust is, for example, used as the metal oxide.

A rotary hearth furnace is, for example, used as the moving hearth-type reduction melting furnace.

It is preferable that the moving hearth-type reduction melting furnace comprises a upstream area having a temperature controlled to be from 1300°C to 1450°C and a downstream area having a temperature controlled to be from 1400°C to 1550°C.

And it is preferable that the downstream area is set to have a temperature higher than that of the upstream area in the moving hearth-type reduction melting furnace.

EFFECT OF THE INVENTION

[0011] In the present invention, the average diameter of the agglomerates fed onto the hearth and the spread density of the agglomerates heated on the hearth are appropriately controlled, which improves the productivity of the granular metal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

FIG. 1 is a plan view schematically showing agglomerates spread on a hearth.

FIG. 2 includes pictures in substitution for drawings, which show states where agglomerates having the average diameter of 18.2 mm are spread.

FIG. 3 is a graph indicating the relationship between the distance "r" of adjacent agglomerates and the projected area ratio or spread density.

FIG. 4 is a graph indicating the relationship between the spread density and the amount of agglomerates fed to a furnace.

FIG. 5 is a graph indicating the relationship between an average diameter (Dp) of a test material (i.e., agglomerates) and reaction time.

FIG. 6 is a graph indicating the relationship between the average diameter of agglomerates and the productivity index in a case where granular metallic iron is produced from the agglomerates spread at a constant density.

FIG. 7 is a graph indicating the relationship between the average diameter of agglomerates and the productivity index when granular metallic iron is produced from the agglomerates (i.e., a test material) apart from each other at the constant distance "r" in the hearth.

MODE FOR CARRYING OUT THE INVENTION

[0013] The inventor of the present application conducted diligent investigations to improve the process for producing granular metal by feeding onto a hearth of a moving hearth-type reduction melting furnace and heating thereon agglomerates containing a metal oxide and a carbonaceous reducing agent to reduce and to melt the metal oxide included in the agglomerates. The inventor finally found out that the productivity of the granular metal can be improved by:

- (1) preparing the agglomerates so as to have an average diameter of not smaller than 17.5 mm; and
- (2) heating the agglomerates that are spread on the hearth at the spread density of not lower than 0.5, to achieve the present invention. The details of the achievement of the present invention are described below.

[0014] In the above Patent Document, when metallic iron is produced by heating and reducing formed products containing a carbonaceous reducing agent and iron oxide, pellets (i.e., agglomerates) having an average diameter of 17 mm are used as the formed products. The reason why the agglomerates having an average diameter of 17 mm are used has been thought to be that agglomerates of a larger size will require longer time to transfer heat to the agglomerates on the hearth in the furnace, resulting in a longer reaction time and therefore the deterioration in the productivity of granular metallic iron.

[0015] However, the inventor of the present application investigated in more detail on the relationship between the size of the agglomerates and the productivity to find a new fact that the productivity of granular metal can be better improved with use of agglomerates having an average diameter of not smaller than 17.5 mm. This new finding is described with reference to FIG. 7.

[0016] FIG. 7 is a graph referred to in an example to be described later, indicating the relationship between the average diameter of agglomerates and the productivity index. In FIG. 7, the productivity index is a relative value to the productivity that is set to 1.00 in a case where granular metallic iron is produced with use of agglomerates having the average diameter of 17.5 mm (i.e., 1.75 cm). This productivity represents a quantity of granular metallic iron produced per unit area of the effective hearth per unit time (to be detailed later).

[0017] As apparent from FIG. 7, the productivity index is larger and the productivity of granular metallic iron is improved by using agglomerates having an average diameter of not smaller than 17.5 mm (more specifically, an average diameter from 17.5 to 32.0 mm) in comparison to the case of using agglomerates having the average diameter of 16.0 mm (i.e., 1.60 cm).

[0018] FIG. 7 indicates a result of re-evaluation (i.e., simulation), on the basis of the results of various experiments, of the relationship in the cases where the distance "r" between the adjacent agglomerates on the hearth is kept constant (in other words, when the agglomerates are spread on the hearth at different spread density). The spread density is the density of filled agglomerates that are spread per unit area of the effective hearth, and can be calculated from the projected area of the agglomerates on the hearth (to be detailed later). FIG. 7 indicates the result of re-evaluation on the basis of the result indicated in FIG. 5. As seen from the relationship between the average diameter and the reaction time indicated in FIG. 5, each of the actual measurement values is slightly varied. Therefore, there was applied the normalization of the relationship between by the approximation thereof with a curve that is used in the re-evaluation. This is one of the approaches of scientific analyses.

[0019] The most important factors in the evaluation of the productivity of granular metal are the reaction time and the yield rate (in other words, the product recovery rate). Accordingly, these properties are particularly normalized in accordance with the experimental data to conduct the re-evaluation. It is noted that the apparent density of agglomerates is another important factor that influences the productivity. However, it is preliminarily evaluated that agglomerates having a diameter from 16.0 to 32.0 mm, for example, have small variations in the apparent density as long as the agglomerates are prepared by using an identical agglomeration method, and that the apparent density can be therefore regarded as being substantially constant in the comprehensive evaluation. According to FIG. 7, as will be referred to in the example to be described later, the spread density of agglomerates is increased as the average diameter of the agglomerates is larger (see Table 6 below). Therefore, it is understood from FIG. 7 that the productivity of granular metallic iron can be improved by appropriately controlling the spread density, as well as by the control of the average diameter of agglomerates. Consequently, the present invention clarifies that the productivity of granular metallic iron can be improved by the control of the spread density as well as the average diameter of agglomerates.

[0020] Described in detail below is the producing method according to the present invention.

[0021] Prepared in the present invention are agglomerates having an average diameter of not smaller than 17.5 mm.

[0022] The agglomerates are prepared by agglomerating a mixture containing a metal oxide and a carbonaceous reducing agent. The metal oxide may be an iron oxide-containing material, chromium-containing ore, nickel-containing ore, or the like. In particular, what can be used as the iron oxide-containing material is iron ore, iron sand, steelmaking dust, nonferrous smelting residue, steelmaking waste, or the like. The carbonaceous reducing agent may be a carbon-containing material such as coal or coke.

[0023] The mixture may be blended with an additional component such as a binder, an MgO-containing material, or a CaO-containing material. The binder may be a polysaccharide (e.g., starch such as flour). The MgO-containing material may be powdered MgO, those extracted from natural ore, seawater, or the like, magnesium carbonate (i.e., MgCO_3) or the like. The CaO-containing material may be quicklime (i.e., CaO), limestone (i.e., composed mostly of CaCO_3), or the like.

[0024] The agglomerates are prepared to have an average diameter of not smaller than 17.5 mm. If the average diameter of the agglomerates is smaller, the time required to the heat transfer in the furnace is shortened in general, which also shorten the reaction time. However, when the average diameter of the agglomerates is small, it is difficult to spread the agglomerates evenly on the carbonaceous material laid on the hearth. Moreover, the particle diameter and unit mass of granular metal are inevitably decreased, which granular metal is obtained by heating the agglomerates. Such small granular metal obtained by said heating step needs to be handled with special care, which results in the

difficulty in feeding the granular metal into a finery such as an electric furnace or a converter. Furthermore, the small granular metal is not preferable in view of the melting property. Therefore, the present invention uses agglomerates having an average diameter of not smaller than 17.5 mm. The average diameter of the agglomerates is preferably not smaller than 18.5 mm, more preferably not smaller than 19.5 mm, and further preferably not smaller than 20 mm. There is no particular upper limit to the average diameter of agglomerates. Nevertheless, such agglomerates having an average diameter of more than 32 mm require too much time for the heat transfer in the furnace, resulting in longer reaction time and deterioration in productivity. In addition, the larger average diameter of agglomerates tends to deteriorate the granulation efficiency. Therefore, the agglomerates are preferably prepared to have an average diameter of not more than 31 mm. The average diameter of the agglomerates is more preferably not more than 28 mm.

[0025] There is no particular limitation to the shape of the agglomerates, which may be in the shape of pellets, briquettes, or the like.

[0026] In order to obtain the diameter of each of the agglomerates, the longer diameter of the agglomerate and the shorter diameter thereof in the direction perpendicular to the longer diameter are measured with use of a vernier caliper, and these longer and shorter diameters are averaged [diameter = (longer diameter + shorter diameter)/2]. The average diameter of the agglomerates is obtained by measuring and averaging the diameters of at least 20 particles with use of the vernier caliper. In a case where the average diameter of the agglomerates is equal to α mm, the diameters (absolute values) of the agglomerates are preferably distributed in the range of $\alpha \pm 5$ mm.

[0027] It is important in the present invention to heat agglomerates having an average diameter of not smaller than 17.5 mm which are spread on the hearth at the density of not lower than 0.5 on the hearth. It has been conventionally recognized that agglomerates having a larger average diameter deteriorate the productivity. However, the present invention has clarified the extremely important fact contradictory to the conventional common knowledge, as to be proved in the examples later. That is, the productivity is improved in a case where agglomerates having an average diameter of not smaller than 17.5 mm are heated at the spread density of not lower than 0.5 on the hearth. However, if the spread density of agglomerates is lower than 0.5, the density of the agglomerates spread per unit area of the effective hearth is too small. In this case, the amount of granular metal generated is totally decreased even though the particle diameter is increased to be not smaller than 17.5 mm, which leads to failure in improving the productivity. Accordingly, agglomerates need to be spread at the density of not lower than 0.5. The spread density is desirably set to be as large as possible, and is preferably not lower than 0.6. There is no particular upper limit to the spread density of agglomerates. However, if agglomerates are fed at a spread density of more than 0.8, such agglomerates may be laid in two or more layers. In this case, it is difficult to evenly heat the agglomerates, which results in difficulty in producing granular iron of high quality. Therefore, the spread density of agglomerates is preferably set to have the upper limit of 0.8, and is more preferably not more than 0.7.

[0028] The spread density of agglomerates is described in detail below. The spread density of agglomerates is calculated from the projected area ratio, relative to the hearth, of the agglomerates spread on the hearth. Described below is the method of calculating the spread density with reference to FIG. 1.

[0029] FIG. 1 is a plan view schematically showing agglomerates spread on the hearth. The projected area ratio of the agglomerates onto the hearth can be calculated by equation (1).

$$\text{Projected area ratio (\%)} = [\text{projected area of all agglomerates on hearth} / \text{effective hearth area}] \times 100 \quad \dots (1)$$

[0030] The agglomerates are assumed to have a perfectly spherical shape, and the average diameter of the agglomerates and the distance of the adjacent agglomerates are expressed by D_p and r , respectively, the projected area ratio of the agglomerates onto the hearth can be calculated by the following equation (2):

$$\text{Projected area ratio (\%)} = \pi \times (D_p)^2 / \{(D_p + r) \times (D_p + r) \times 3^{0.5} / 2\} \times 100 (\%) \quad \dots (2)$$

[0031] In a case where the distance " r " between the adjacent agglomerates is set to 0, the projected area ratio has the maximum value and the maximum projected area ratio has a constant value (i.e., 90.69%). Assuming that the maximum projected area ratio is equal to 1, the present invention defines, as the spread density, a relative value of the projected area ratio that is calculated in accordance with equation (2) from the average diameter D_p of the agglomerates and the distance " r " between the adjacent agglomerates.

[0032] In order to describe the actual cases of the spread density in more detail, FIG. 2 shows states where agglomerates having the average diameter of 18.2 mm are spread in containers each in a flat plate shape of approximately 61 cm square.

[0033] Case (a) in FIG. 2 shows an example of filling in a container agglomerates weighing 9.3 kg per unit area of 1 m², in which case the spread density was equal to 0.4. The theoretical amount of agglomerates filled at the spread density of 0.4 weighs 9.33 kg per unit area of 1 m². It is therefore found out that the filled amount and the spread density in Case (a) is substantially equal to the theoretical values.

[0034] Case (b) in FIG. 2 shows an example of filling in a container agglomerates weighing 13.9 kg per unit area of 1 m², in which case the spread density was equal to 0.6. The theoretical amount of agglomerates filled at the spread density of 0.6 weighs 14.0 kg per unit area of 1 m². It is therefore found out that the filled amount and the spread density in Case (b) is substantially equal to the theoretical values.

[0035] Case (c) in FIG. 2 shows an example of filling in a container agglomerates weighing 18.5 kg per unit area of 1 m², in which case the spread density was equal to 0.8. The theoretical amount of agglomerates filled at the spread density of 0.8 weighs 18.66 kg per unit area of 1 m². It is therefore found out that the filled amount and the spread density in Case (c) is substantially equal to the theoretical values.

[0036] Case (d) in FIG. 2 shows an example of filling in a container agglomerates weighing 23.2 kg per unit area of 1 m², in which case the spread density was equal to 1.0. The theoretical amount of agglomerates filled at the spread density of 1.0 weighs 23.33 kg per unit area of 1 m². It is therefore found out that the filled amount and the spread density in Case (d) is substantially equal to the theoretical values.

[0037] It is quite difficult to spread agglomerates on an actual hearth at the spread density of 1.0 as shown in Case (d) of FIG. 2. In an actual case where agglomerates are fed to a furnace in the amount of the spread density equal to 1.0, there is caused another problem such as the charged agglomerates being overlaid with each other. In order to feed agglomerates to the furnace so as not to be overlaid with each other, it was found out, through the various demonstration experiments, that the upper limit of the spread density was preferably set to approximately 0.8, as shown in Case (c) of FIG. 2.

[0038] On the other hand, as shown in Case (a) of FIG. 2, the spread density equal to 0.4 causes quite a large number of spaces on the hearth, which will extremely deteriorate the productivity. Thus, the ideal lower limit of the spread density will be approximately 0.5, which is an intermediate value of those of Case (a) and Case (b) in FIG. 2.

[0039] FIG. 3 indicates the relationship between the distance "r" of adjacent agglomerates and the projected area ratio or spread density. In FIG. 3, the marks • indicate the results of projected area ratios, while the marks □ indicate the results of spread densities. As apparent from FIG. 3, as the distance "r" between the adjacent agglomerates is increased, both the projected area ratio and the spread density of the agglomerates are reduced. There is recognized a favorable correlation between the projected area ratio and the spread density relative to the distance "r" between the adjacent agglomerates.

[0040] FIG. 4 indicates the relationship between the spread density and the amount of agglomerates fed to the furnace in a case where the average diameter of the agglomerates is changed in the range from 14.0 to 32.0 mm. The amount of the fed agglomerates is indicated by the mass of the fed agglomerates in the effective hearth area.

[0041] In FIG. 4, a straight line connecting a point (A) and a point (B) indicates a range of the amount of agglomerates fed to the furnace in a case where the agglomerates have an average diameter of not smaller than 17.5 mm and are spread at the density of 0.5. A straight line connecting a point (C) and a point (D) indicates a range of the amount of agglomerates fed to the furnace in a case where the agglomerates have an average diameter of not smaller than 17.5 mm and are spread at the density of 0.8. As can be seen from this FIG. 4, the average diameter of the agglomerates and the amount of agglomerates to be fed to furnace (i.e., the mass of agglomerates to be fed per effective hearth area) may be adjusted to control the spread density of the agglomerates on the hearth to not lower than 0.5.

[0042] The agglomerates are heated in a moving hearth-type reduction melting furnace to reduce and to melt a metal oxide in the agglomerates so as to manufacture granular metal. The moving hearth-type reduction melting furnace and the heating condition in the furnace are not particularly limited in the present invention, and there can be adopted a known condition.

[0043] As the above moving hearth-type reduction melting furnace, there can be used, for example, a rotary hearth furnace. There is no particular limitation to the width of the hearth of the moving hearth-type reduction melting furnace. According to the present invention, it is possible to improve the productivity of granular metal under an economically advantageous condition even with use of an actual machine having a hearth width of not smaller than 4 m.

[0044] It is preferable to spread the carbonaceous material (hereinafter, also referred to as bed material) on the hearth and then to feed the agglomerates on the carbonaceous material, so that the agglomerates are fed to form a single layer on the carbonaceous material layer. The bed material serves as a carbon resource in a case where the carbon included in the agglomerates is not sufficient, and also serves as a hearth protective material.

[0045] Although there is no particular limitation to the thickness of the bed material, the thickness is preferably not less than 3 mm. More specifically, in a case where the moving hearth-type reduction melting furnace is actually used,

the hearth width will have several meters. Accordingly, it is difficult to spread evenly the bed material across the width direction and there may be caused variations in thickness from about 2 to 8 mm. It is preferable to spread the bed material so as to have a thickness of not less than 3 mm in order to cause no portion on the hearth not covered with the bed material. The thickness of the bed material is more preferably not less than 5 mm, and further preferably not less than 10 mm. Because the present invention uses particularly large agglomerates, such agglomerates are unlikely to be buried even in the bed material having a large thickness, and the reduction efficiency will be hardly deteriorated. More specifically, the bed material having a larger thickness is particularly effective in a case of using agglomerates that have an average diameter of not less than 20 mm. There is no particular limitation either to the upper limit of the thickness of the bed material. However, if the thickness of the bed material is more than 30 mm, agglomerates may be buried in the bed material even in the present invention, which may inhibit the supply of heat to the agglomerates and thus deteriorate the reduction efficiency. As a result, granular metal is likely to be deformed or deteriorated in interior quality thereof. Therefore, the thickness of the bed material is preferably not more than 30 mm, more preferably not more than 20 mm, and further preferably not more than 15 mm.

[0046] The carbonaceous material used as the bed material can be selected from those exemplified as the carbonaceous reducing agent. The carbonaceous material desirably has a particle diameter of not more than 3.0 mm, for example. If the particle diameter of the carbonaceous material is more than 3.0 mm, the molten slag may flow down through the spaces in the carbonaceous material to reach the surface of the hearth and erode the hearth. The particle diameter of the carbonaceous material is more preferably not more than 2.0 mm. However, if the proportion of the particles having a diameter of smaller than 0.5 mm is too large in the carbonaceous material, the agglomerates will be buried in the bed material to lead to the deteriorations in heating efficiency as well as in productivity of granular metal, which is not preferable.

[0047] The agglomerates are preferably fed onto the hearth so as to form a single layer over the bed material that is spread on the hearth. One general idea for the increase in the production quantity of granular metallic iron will be increasing the amount of agglomerates to be fed to the furnace. In such a case of increasing the amount of fed agglomerates, the agglomerates are stacked into two or more layers on the hearth. In this case, the upper agglomerates receive sufficient heat from a furnace body to be reduced and melted, while sufficient heat is not fed to the lower agglomerates, which are likely to cause residual portions not having been reduced. If molten iron obtained only from the reduced and melted upper agglomerates is combined with the lower un-melted and un-reduced iron and the like, it is impossible to obtain granular metallic iron of high quality. Therefore, in order to reliably achieve reduction in the solid state as well as carburizing and melting inside the furnace as in the present invention, it is desirable to feed agglomerates onto the hearth so as to form substantially a single layer.

[0048] Upon feeding agglomerates onto the hearth so as to form a single layer, a pellet leveler or the like may be used to control the agglomerates to be spread on the hearth so that the agglomerates are evenly spread over the effective hearth across the width direction thereof before the agglomerates fed to the furnace enter a thermal reaction zone.

[0049] It is possible to apply a common heating condition to the case where the agglomerates are heated in a moving hearth-type reduction melting furnace to reduce and to melt the metal oxide included in the agglomerates. More specifically, the agglomerates are fed onto the hearth, reduced in the solid state at a predetermined temperature, and further continuously heated until being melted, so as to obtain manufactured slag (i.e., oxide) comprising impurities and granular metallic iron. The agglomerates on the hearth receive heat from combustion flames of a plurality of burners installed in an upper portion in the furnace (e.g., on a ceiling) or on a side wall, or radiation heat from a refractory material in the furnace, which is heated to a high temperature. The received heat is transferred from the peripheral portions to the inner portions of the agglomerates so as to progress the reduction reaction in the solid state.

[0050] In the upstream area in the furnace, the reduction reaction progresses while the agglomerates being kept in the solid state. In the downstream area in the furnace, microscopic particles of reduced iron in the agglomerates, which have been already reduced in the solid state, are carburized and then coalesced to each other in the process of being melted, so as to form granular metallic iron while being separated from the impurities (i.e., slag components) in the agglomerates.

[0051] The temperature of the upstream area in the furnace is preferably controlled to be at approximately 1300°C to 1450°C so as to cause the iron oxide in the agglomerates to be reduced in the solid state. The temperature of the downstream area in the furnace is preferably controlled to be at approximately 1400°C to 1550°C so as to cause the reduced iron in the agglomerates to be carburized, melted, and coalesced. If the furnace is heated to be higher than 1550°C, heat is excessively applied to the agglomerates to exceed the rate of the heat transferred into the agglomerates. In this case, the agglomerates are partially melted before being completely reduced in the solid state. As a result, the reaction progresses rapidly to cause a molten reduction reaction, which generates abnormal slag formation.

[0052] The downstream area in the furnace may be set to a temperature higher than that in the upstream area in the furnace.

[0053] In the present invention, the productivity of the case where the agglomerates are heated to reduce and to melt the metal oxide to produce granular metal is evaluated by the production quantity (ton) of the granular metal per unit area (m²) of the effective hearth per unit time (time), as expressed by equation (3) below.

Productivity (ton/m²/time) = production quantity of granular metal (granular-metal
 5 ton/time)/effective hearth area (m²) ... (3)

[0054] In equation (3), the production quantity of granular metal (granular-metal ton/time) is expressed by equation (4) below.

10 Production quantity of granular metal (granular-metal-ton/time) = amount of
 agglomerates charged (agglomerates-ton/time) × mass of granular metal produced from
 15 1 ton of agglomerates (granular-metal-ton/ agglomerates-ton) × product recovery
 rate ... (4)

20 [0055] In equation (4), the product recovery rate is calculated as a proportion of granular metallic iron having a diameter of not smaller than 3.35 mm to the total mass of the granular metal obtained [mass of granular metallic iron having a diameter of not smaller than 3.35 mm/total mass of granular metallic iron × 100].

[0056] In Experimental Examples 2 and 3 in the examples to be described later, in order to quantitatively evaluate the effects of the present invention, a test material (i.e., agglomerates) having the average diameter of 17.5 mm is regarded
 25 as including standard agglomerates, and the productivity of each of the agglomerates is indicated as a relative value (i.e., productivity index) in a case where the productivity of the standard agglomerates is set to 1.00.

[0057] The present invention will be described in more detail with reference to the examples. It is noted that the present invention is never limited to the following examples but can be of course embodied with appropriate modifications as long as being adaptable to the purposes of the above statement and the following statement. Such modifications are
 30 also included in the technical scope of the present invention.

Examples

Experimental Example 1

35 [0058] Agglomerates were prepared from a raw material mixture containing a metal oxide and a carbonaceous reducing agent, and the agglomerates were fed onto a hearth of a moving hearth-type reduction melting furnace and were heated thereon to reduce and to melt the metal oxide in the raw material mixture, so as to produce granular metallic iron.

[0059] In this case, iron ore having the component compositions listed in Table 1 below was used as the metal oxide, and coal having the component compositions listed in Table 2 below was used as the carbonaceous reducing agent, to
 40 produce the agglomerates. More specifically, the mixture containing the iron ore and the coal was blended with flour serving as a binder and an auxiliary material such as limestone or dolomite, to produce agglomerates (i.e., test materials) in the shapes of pellets having different average diameters. The blend compositions (i.e., weight percentages) of the test materials are listed in Table 3 below. Further, the longer diameters and the shorter diameters of the test materials were measured with use of a vernier caliper to calculate the average diameters, which are listed in Table 4 below. Each
 45 of the average diameters of the test materials is obtained by measuring the sizes of 20 particles of each of the test materials.

[0060] There are also listed in Table 4 unit mass and an apparent density of each of the test materials. The unit mass of each of the test materials is equal to an average value obtained by measuring the mass of 20 particles. The apparent density of each of the test materials is obtained by immersing the agglomerates in a liquid (i.e., mercury) and measuring
 50 buoyant forces thereof.

[0061] Each of the test materials thus obtained and having the different average diameters was heated in a small heating furnace on a laboratory scale (i.e., the temperature in the furnace being set to 1450°C) to reduce and to melt the iron ore included in the corresponding test material, in order to measure time required for the reaction (i.e., reaction time). The measurement results on the reaction time are listed in Table 4 below.

55 [0062] FIG. 5 indicates the relationship between the average diameter (Dp) and the reaction time of the test material. In FIG. 5, a dotted curve shows an approximated curve including plotted points, which is expressed by a quadratic of the average diameter of the test material. As apparent from FIG. 5, as the average diameter of the test material increases, the reaction time is longer.

[0063] According to the results of Experimental Example 1, the reaction time and the product recovery rate were normalized to comprehensively evaluate the productivity of a case where the distance between the adjacent particles of the test material is changed (see Experimental Example 2 to be described later), or of a case where the spread density of the test material is changed (see Experimental Example 3 to be described later).

[0064]

Table 1

Iron ore	Component composition (mass%)									
	Total Fe	FeO	SiO ₂	CaO	Al ₂ O ₃	MgO	MnO	TiO ₂	P	S
	67.73	29.40	4.54	0.42	0.21	0.47	0.34	0.07	0.018	0.002

[0065]

Table 2

Coal	Component composition (mass%)			
	Fixed carbon	Volatile	Ash	Total
	77.21	16.65	6.14	100

[0066]

Table 3

Test material	Blend composition (mass%)			
	Iron ore	Coal	Binder	Auxiliary material
	71.95	17.01	0.90	11.55

[0067]

Table 4

No.	Average diameter (mm)	Unit mass (g/Piece)	Apparent density (g/cm ³)	Reaction time (min)
1	17.3	6.06	2.23	8.7
2	18.8	7.58	2.19	8.8
3	19.4	8.46	2.21	9.0
4	21.3	11.16	2.21	10.0
5	23.1	14.60	2.27	10.7
6	25.2	18.77	2.24	12.0
7	27.0	22.98	2.23	13.2

Experimental Example 2

[0068] In Experimental Example 2, test materials, which have average diameters of 16.0 to 28.0 mm (i.e., 1.60 to 2.80 cm) and are spread at a constant density on a hearth, were heated in an actual moving hearth-type reduction melting furnace to produce granular metallic iron. Comprehensively investigated was how the average diameter of the test material influences on the productivity of granular metallic iron thus produced.

[0069] A rotary hearth furnace was used as the moving hearth-type reduction melting furnace, and each of the test materials was fed onto the hearth at the spread density of 0.66 and was heated thereon to reduce and to melt iron ore so as to produce granular metallic iron. The temperature of the upstream area in the furnace was set to 1400°C and the temperature of the downstream area thereof was set to 1470°C. In the upstream area, the iron ore in the test material is reduced in the solid state. In the downstream area, microscopic particles of reduced iron, which are generated and

melted in the test material, are carburized, melted, and eventually coalesced so as to separate molten iron from slag.

[0070] The spread density of the test material on the hearth was controlled by regulating the amount of the test material fed to the furnace and the moving speed (i.e., rotating speed) of the hearth. More specifically, the moving speed of the hearth was determined such that the iron ore was reduced and melted in the heating zone under an atmospheric condition set in accordance with the result of the preliminary experiment. The supply amount of the test material was regulated in consideration of this moving speed, so that the spread density of the test material on the hearth was controlled to 0.66. Table 5 below shows the distance "r" between the adjacent particles of the test materials as reference values.

[0071] The productivity of granular metallic iron produced by reducing and melting each of the test materials was calculated in accordance with above equation (3), and the productivity of each of the test materials was indicated as a relative value (i.e., productivity index), assuming that the productivity of the test material No. 12 (i.e., standard agglomerates) has a standard value (i.e., productivity index equal to 1.00). The productivity indices of the respective test materials are listed in Table 5 below. Further, FIG. 6 indicates the relationship between the average diameter and the productivity index of the test material.

[0072] As apparent from FIG. 6, when the spread density on the hearth is kept constant, the productivity can be improved by setting the average diameter of the test material to be not smaller than 17.5 mm in comparison to the case of setting the average diameter of the test material to 16.0 mm. In other words, the productivity is gradually improved as the average diameter of the test material increases, and the productivity index reaches the maximum value in the case where the average diameter of the test material equal to 22.0 mm.

[0073] However, if the average diameter of the test material is set to be larger than 26.0 mm, the productivity of granular metallic iron tends to be gradually deteriorated. The productivity will be deteriorated because the reaction time is longer with the test material of a larger size. Accordingly, when the spread density is kept constant, it is found that the productivity can be improved by setting the average diameter of the test material to the range from 17.5 to 26.0 mm in comparison to the case of using the test material having the average diameter of 16.0 mm.

[0074]

Table 5

No.	Average diameter (cm)	Distance "r" (cm)	Spread density (-)	Productivity index
11	1.60	0.37	0.66	0.93
12	1.75	0.37	0.66	1.00
13	1.81	0.42	0.66	1.02
14	1.90	0.44	0.66	1.05
15	2.00	0.46	0.66	1.07
16	2.20	0.50	0.66	1.08
17	2.40	0.55	0.66	1.05
18	2.60	0.60	0.66	1.01
19	2.80	0.64	0.66	0.95

Experimental Example 3

[0075] In Experimental Example 3, assuming test materials each having an average diameter of 16.0 to 32.0 mm (i.e., 1.60 to 3.20 cm), adjacent particles of each of the test materials being apart from each other at a constant distance "r" (i.e., 0.42 cm) on the hearth were heated to produce granular metallic iron in an actual moving hearth-type reduction melting furnace with the spread densities of the test materials being changed. In this manner, investigated was how the spread density of the test material influenced on the productivity of granular metallic iron.

[0076] In the evaluation in this case, a rotary hearth furnace was used as the moving hearth-type reduction melting furnace, and each of the test materials, which have the average diameters listed in Table 6 below and were fed onto the hearth, was heated to reduce and to melt iron ore so as to produce granular metallic iron. The heating condition in the furnace was set identically with that of Experimental Example 2 described earlier. The spread densities of the test materials on the hearth are listed in Table 6.

[0077] The productivity of the granular metallic iron produced by reducing and melting each of the test materials was calculated in accordance with equation (3) above, and the productivity of each of the test materials was indicated as a relative value (i.e., productivity index), assuming that the productivity of the test material No. 22 (i.e., standard agglomerates) has a standard value (i.e., 1.00). The productivity indices of the respective test materials are listed in Table 6

below. Further, FIG. 7 indicates the relationship between the average diameter and the productivity index of the test material.

[0078] As apparent from Table 6 and FIG. 7 below, in the case where the distance "r" between the adjacent particles of the test material is kept constant, the spread density of the test material on the hearth can be increased by setting the average diameter of the test material to be not smaller than 17.5 mm. Further, the productivity of the granular metallic iron can be improved by increasing the average diameter of the test material in comparison to the case of setting the average diameter of the test material to 16.0 mm. In other words, the productivity is gradually improved as the average diameter of the test material increases, and the productivity index reaches the maximum value in the case where the average diameter of the test material is equal to 24.0 mm.

[0079] However, if the average diameter of the test material is larger than 24.0 mm, the productivity of the granular metallic iron tends to be gradually deteriorated. The productivity will be deteriorated because the reaction time is longer with the test material of a larger size. Accordingly, it is found that the productivity can be improved by setting the average diameter of the test material to the range from 17.5 mm to 32.0 mm in comparison to the case of using the test material having the average diameter of 16.0 mm.

[0080]

Table 6

No.	Average diameter (cm)	Distance "r" (cm)	Spread density (-)	Productivity index
21	1.60	0.42	0.63	0.89
22	1.75	0.42	0.65	1.00
23	1.81	0.42	0.66	1.04
24	1.90	0.42	0.67	1.08
25	2.00	0.42	0.69	1.12
26	2.20	0.42	0.71	1.17
27	2.40	0.42	0.73	1.17
28	2.60	0.42	0.74	1.15
29	2.80	0.42	0.76	1.10
30	3.00	0.42	0.77	1.05
31	3.20	0.42	0.78	0.99

[0081] The following conclusion can be obtained by combining the results of Experimental Examples 2 and 3. As described in Experimental Example 2, when using agglomerates having a large average diameter (e.g., agglomerates having an average diameter of more than 28.0 mm), the productivity of granular metallic iron may be deteriorated at a constant spread density. However, as described in Experimental Example 3, if the spread density is increased, the productivity can be improved even in the case of using the agglomerates having an average diameter of more than 28.0 mm. In summary, the productivity can be improved by feeding onto the hearth at a spread density of not lower than 0.5 the agglomerates (i.e., test material) having an average diameter of not smaller than 17.5 mm and heating the agglomerates on the hearth. In other words, it is possible to productively produce granular metallic iron by preparing agglomerates having an average diameter of not smaller than 17.5 mm and feeding the agglomerates onto the hearth at a spread density of not lower than 0.5 to heat the same in the furnace.

INDUSTRIAL APPLICABILITY

[0082] The present invention is applicable to improve the productivity of the granular metal.

Claims

1. A process for producing granular metal comprising the steps of:

feeding agglomerates containing a metal oxide and a carbonaceous reducing agent onto a hearth of a moving hearth-type reduction melting furnace;

heating the agglomerates to reduce and to melt the metal oxide;
cooling the granular metal obtained by said heating step; and
discharging the cooled granular metal out of the furnace to recover the same,
wherein the agglomerates having an average diameter of not smaller than 17.5 mm are fed onto the hearth
when the agglomerates are heated at a spread density of not lower than 0.5 on the hearth.

2. The process according to claim 1, wherein a carbonaceous material is spread on the hearth and then the agglomerates are fed on the carbonaceous material to form a single layer.

3. The process according to claim 1 or 2, wherein iron oxide is used as the metal oxide.

4. The process according to claim 1, wherein a rotary hearth furnace is used as the moving hearth-type reduction melting furnace.

5. The process according to claim 1, wherein steelmaking dust is used as the metal oxide.

6. The process according to claim 1, wherein the moving hearth-type reduction melting furnace comprises a upstream area having a temperature controlled to be from 1300°C to 1450°C and a downstream area having a temperature controlled to be from 1400°C to 1550°C.

7. The process according to claim 6, wherein the downstream area is set to have a temperature higher than that of the upstream area in the moving hearth-type reduction melting furnace.

FIG. 1

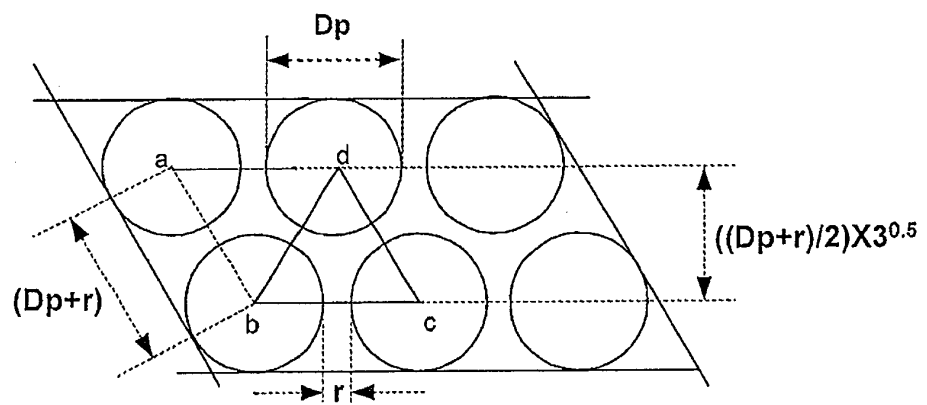


FIG. 2

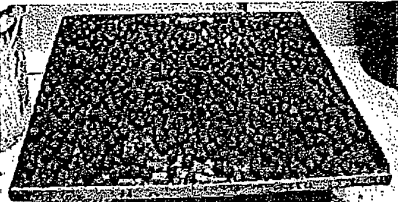
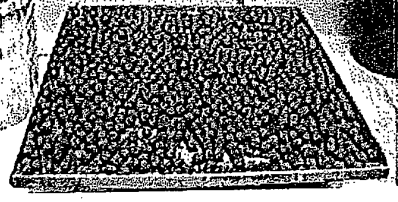
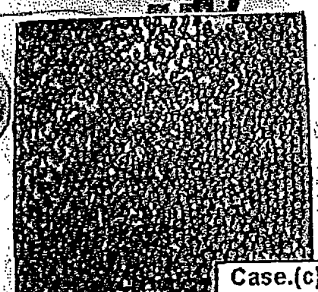
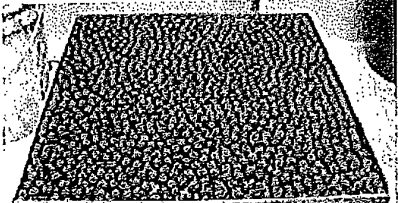
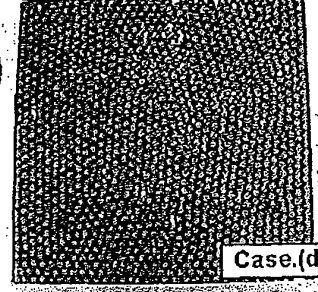
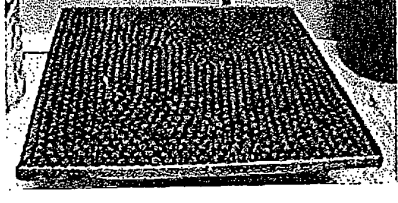
 Case.(a)		Fill ration 9.3kg/m² Spread density 0.4
 Case.(b)		Fill ration 13.9kg/m² Spread density 0.6
 Case.(c)		Fill ration 18.5kg/m² Spread density 0.8
 Case.(d)		Fill ration 23.2kg/m² Spread density 1.0

FIG. 3

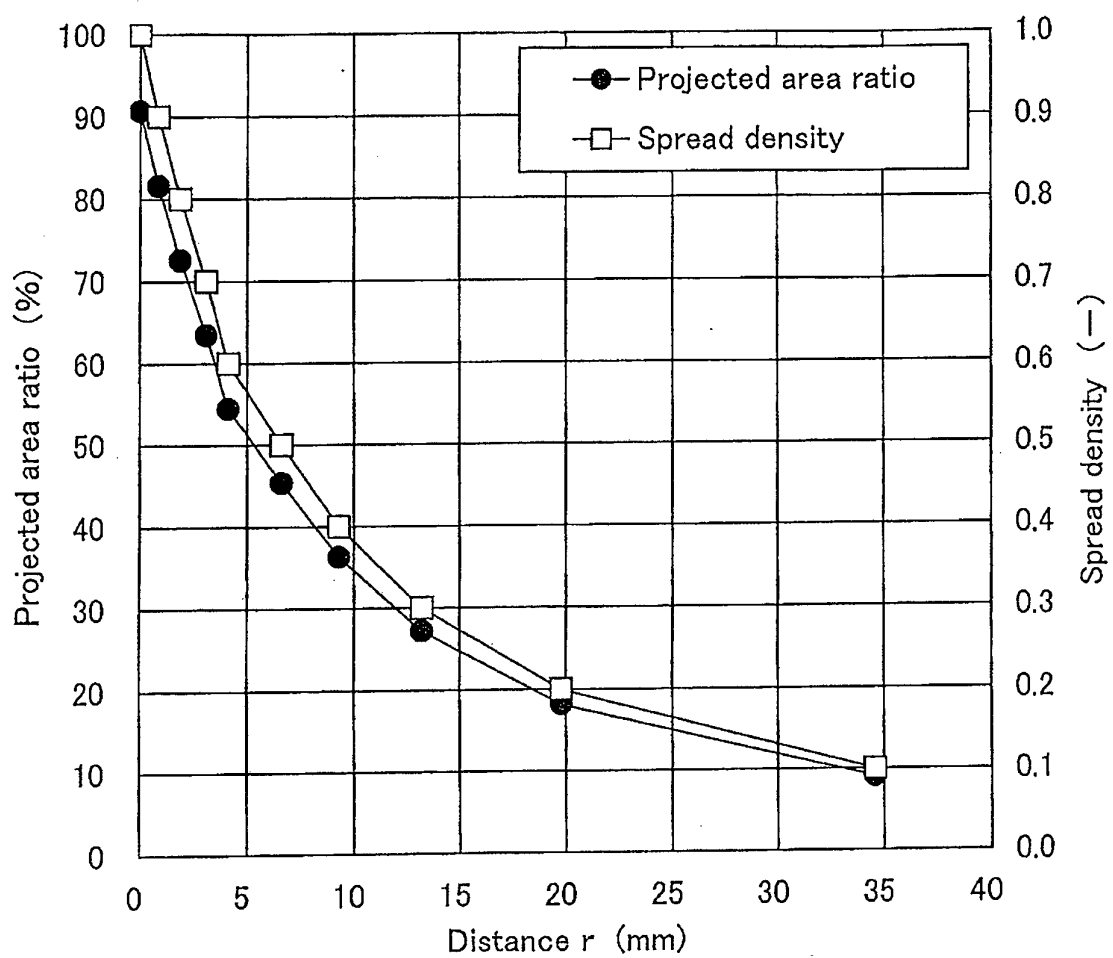


FIG. 4

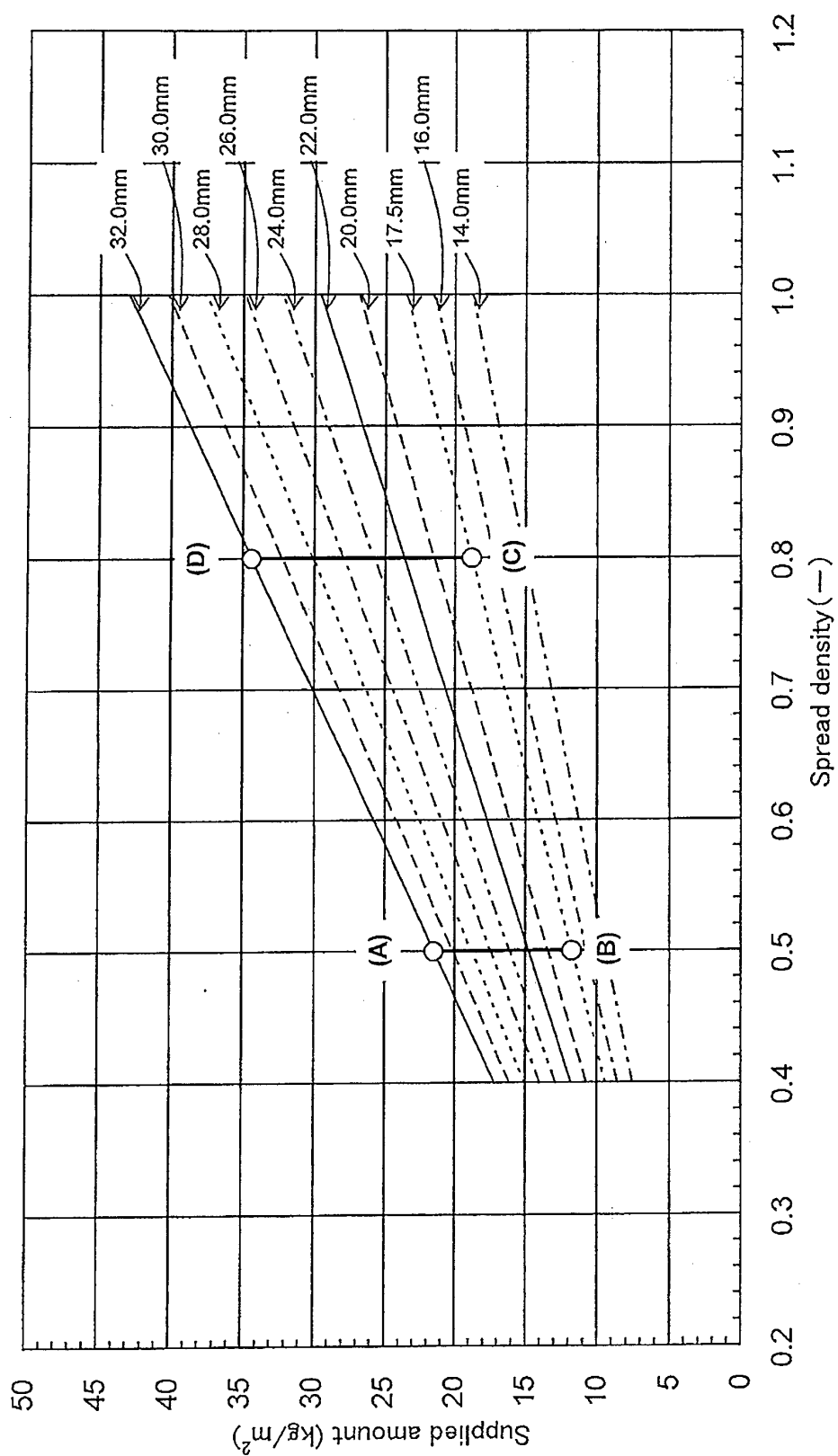
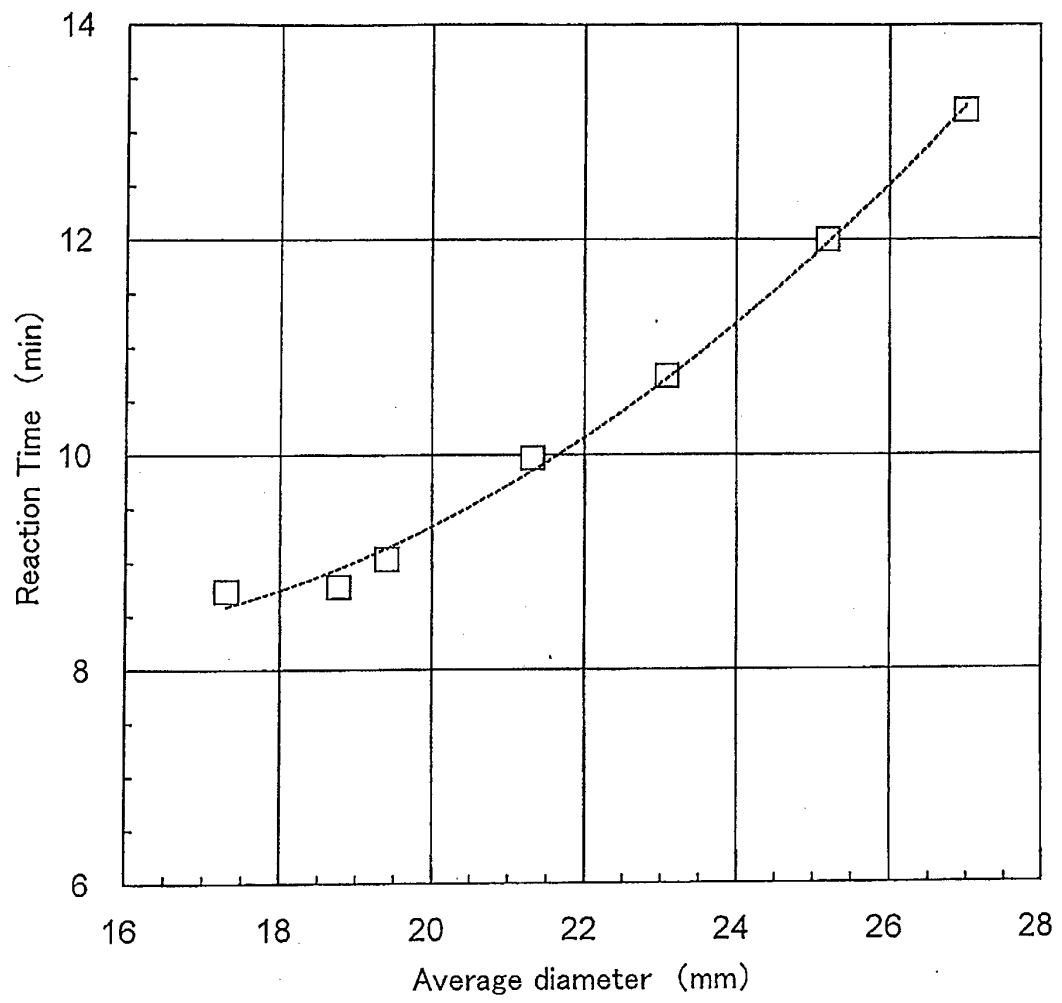


FIG. 5



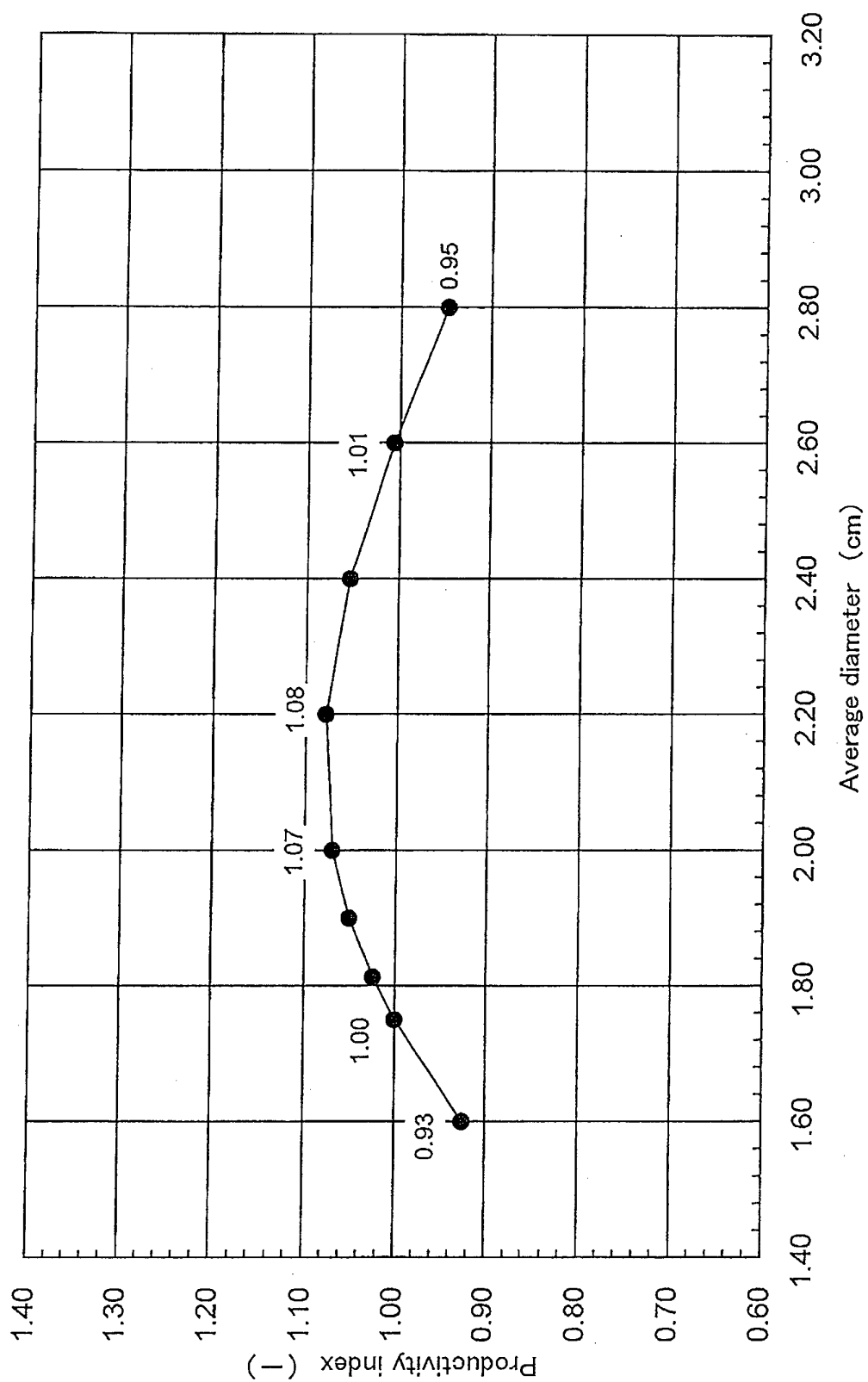
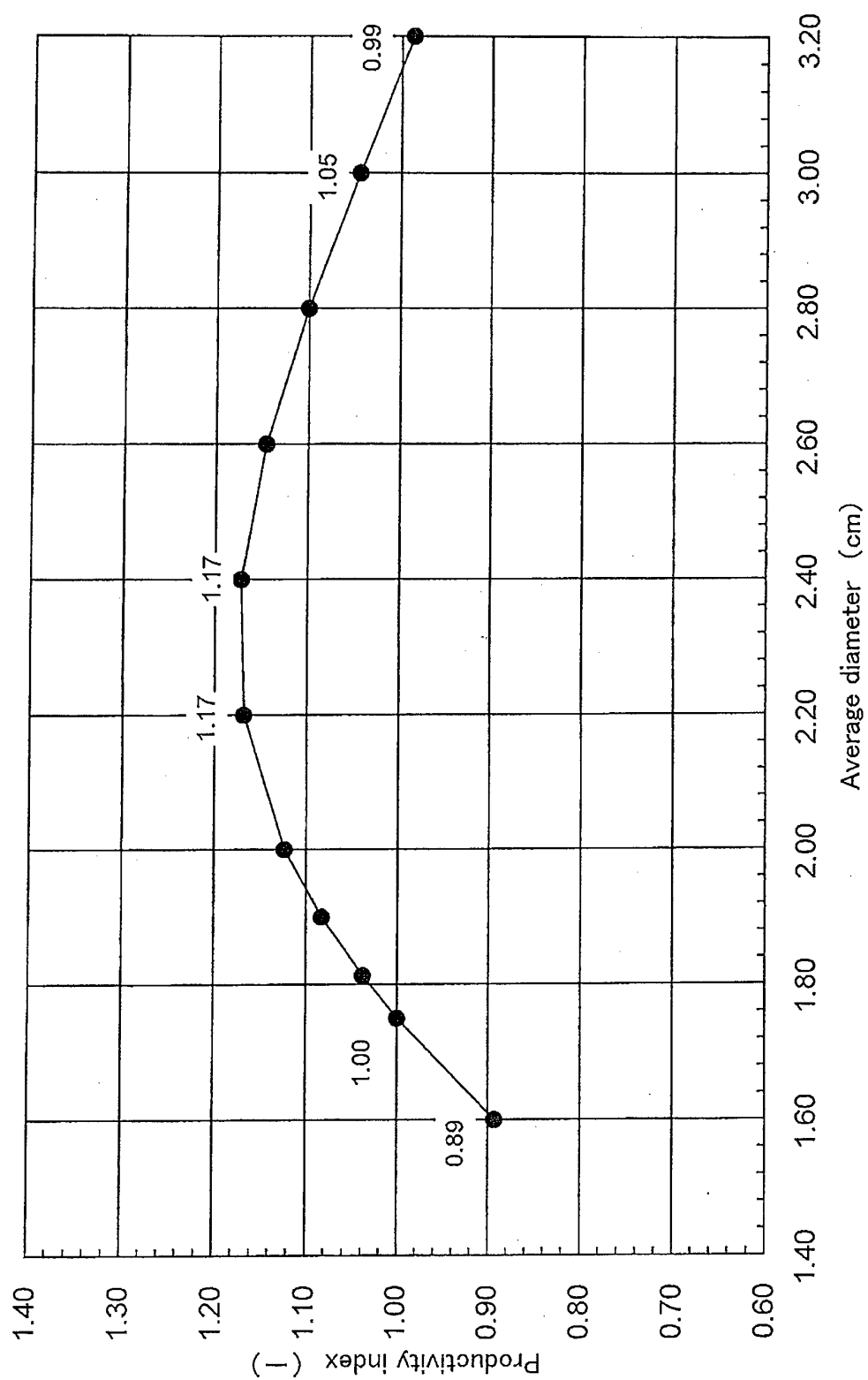


FIG. 6

FIG. 7



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/062847

A. CLASSIFICATION OF SUBJECT MATTER <i>C21B13/10</i> (2006.01)i, <i>C21B11/08</i> (2006.01)i, <i>C22B1/16</i> (2006.01)i, <i>C22B1/248</i> (2006.01)i 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) <i>C21B13/10</i> , <i>C21B11/08</i> , <i>C22B1/16</i> , <i>C22B1/248</i> Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2011 Kokai Jitsuyo Shinan Koho 1971-2011 Toroku Jitsuyo Shinan Koho 1994-2011 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 11-335713 A (Kobe Steel, Ltd.), 07 December 1999 (07.12.1999), paragraphs [0006] to [0008], [0012], [0018], [0022], [0025]; fig. 1, 3 & EP 952230 A1 paragraphs [0006] to [0008], [0012], [0018], [0021], [0023]; fig. 1, 3 & US 6129777 A	1-4 5-7
Y	JP 2001-294921 A (Midrex International B.V.), 26 October 2001 (26.10.2001), paragraphs [0020], [0034] to [0036], [0039] & US 2001/0037703 A1 paragraphs [0041], [0071] to [0073], [0076] & WO 01/077395 A1	5-7
☒ Further documents are listed in the continuation of Box C. ☐ 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 "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 24 August, 2011 (24.08.11)		Date of mailing of the international search report 06 September, 2011 (06.09.11)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/062847

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2000-212619 A (Kobe Steel, Ltd.), 02 August 2000 (02.08.2000), paragraphs [0020] to [0023], [0035], [0048] to [0051], [0055], [0056]; table 3; fig. 3 & EP 1020535 A1 paragraphs [0017] to [0020], [0033], [0045] to [0047], [0051], [0052]; fig. 3, 6 & US 6319302 B1	1-7
A	JP 2006-258350 A (JFE Steel Corp.), 28 September 2006 (28.09.2006), paragraph [0005]; fig. 1 (Family: none)	5-7

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/062847

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/062847

Continuation of Box No.III of continuation of first sheet(2)

In order that a group of inventions set forth in claims comply with the requirement of unity, it is required that a special technical feature for so linking the group of inventions as to form a single general inventive concept is present, but the inventions set forth in claims 1-7, which is a group of inventions set forth in claims, are considered to be linked with one another by only the matter set forth in claim 1.

However, it is obvious that the above-said matter cannot be a special technical feature, since the matter is described in the prior art documents, for example, JP 11-335713 A (Kobe Steel, Ltd.), 7 December 1999 (07.12.1999), [0006]-[0008], [0012], [0018], [0022], [0025], fig. 1, 3, and so on.

Consequently, there is no special technical feature for so linking inventions as to form a single general inventive concept among the group of inventions set forth in claims, and therefore, the group of inventions set forth in claims does not comply with the requirement of unity of invention.

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP H11241111 B [0005]