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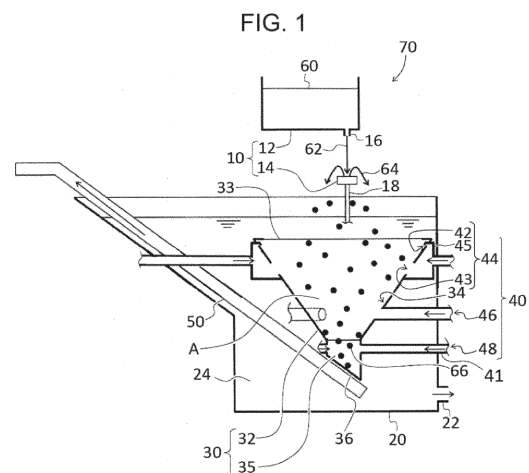
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(54) **GRANULAR IRON MANUFACTURING DEVICE AND GRANULAR IRON MANUFACTURING METHOD**

(57) Provided a granular iron manufacturing apparatus and a granular iron manufacturing method that are capable of suppressing mutual coalescence of granular iron by cooling the granular iron efficiently.

A granular iron manufacturing apparatus 70 includes a water-flow controlling container 30 and a cooling water pipe group 40 configured to supply cooling water 24 into the water-flow controlling container, the water-flow controlling container 30 includes a partition cylindrical body 32 including an inclined surface 34 and a duct cylindrical body 35 connected to a lower portion of the partition cylindrical body 32, the cooling water pipe group 40 includes an upper-level cooling water pipe group 44, a middle-level cooling water pipe group 46, and a lower-level cooling water pipe group 48 that are connected to the partition cylindrical body 32, a first circulating flow circulating inside the partition cylindrical body 32 is generated by the cooling water 24 supplied from the middle-level cooling water pipe group 46 and the upper-level cooling water pipe group 44, and a second circulating flow circulating inside the duct cylindrical body 35 is generated by the cooling water 24 supplied from the lower-level cooling water pipe group 48 and drainage water from the partition cylindrical body 32.



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## Description

### Technical Field

**[0001]** The present invention relates to a granular iron manufacturing apparatus configured to manufacture granular iron from molten iron and a granular iron manufacturing method.

### Background Art

**[0002]** Granular iron is formed by dispersing molten iron such as molten pig iron or molten steel and then by solidifying the dispersed portions into granules, and the average grain size thereof is about several mm to several tens of mm. At an integrated ironworks, when molten pig iron is manufactured unexpectedly in an excessive amount in a blast furnace due to occurrence of a trouble or other events in steelmaking and the downstream processes, such surplus molten pig iron is temporarily stored while being converted into granular iron. In recent years, blast furnaces have been increased in size, and incapability of temporarily processing a large amount of molten pig iron leads to production decrease of the blast furnaces. Thus, a facility serving as a buffer is required in preparation for the case of a trouble or other events that occur in steelmaking and the downstream processes.

**[0003]** In addition, due to the demand for reduction in CO<sub>2</sub> emissions in the recent iron industry, there is an increasing need for reduced iron that is produced by using, as a reducing agent, hydrogen or a hydrocarbon gas-based gas such as natural gas, not by using coke (carbon source). To manufacture steel products from reduced iron at high gangue (mainly SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>) or P concentration, gangue removal or a dephosphorization treatment is indispensable after the manufacturing of reduced iron. Thus, there is a case where, as treatment in preparation for manufacturing steel products, reduced iron is once melted into molten iron, a treatment such as gangue removal or dephosphorization is then performed, and the molten iron after the treatment is stored in form of granular iron that is conveyable.

**[0004]** As a method for granulating molten pig iron, Patent Literature 1 discloses a method for granulating pig iron by spraying molten pig iron with pressurized water. However, there is a risk of steam explosion caused during a time of remelting because, in the method disclosed in Patent Literature 1, a large part of granular iron becomes hollow, and water thus collects in such hollow portions. Patent Literature 2 discloses a granular metal manufacturing method. In the method, molten pig iron is caused to fall onto a fixed board, liquid drops bounce off the fixed board to move upward relative to the fixed board and fall into a cooling bath provided below to be cooled, and granular iron is thus manufactured. Moreover, Patent Literature 3 discloses an apparatus configured to manufacture a large amount of granular iron by granulating molten pig iron with a water flow and by cooling and

solidifying the liquid granular iron through underwater dropping.

**[0005]** The granular iron is at high temperature when being dropped into the water. Since the temperature of the granular iron is about 1200 to 1500°C, when such high-temperature granular iron comes into contact with the water, there is brought about a film boiling state in which a vapor film is formed on a surface of a high-temperature object, and the water takes heat from the granular iron while evaporating. The film boiling has a low cooling capacity and, for example, has a heat transfer coefficient as small as several hundredths of that of nucleate boiling in which no vapor film is formed. Thus, when the film boiling lasts long, the granular iron is failed to be cooled sufficiently, and the iron granules may be mutually fused to coalesce inside the cooling water.

**[0006]** In addition, when the temperature of the cooling water is high, the water easily boils; thus, the vapor film is likely to be maintained around the high-temperature object, which is likely to lead to the film boiling. Thus, when the water temperature of the cooling water is increased, the cooling capacity for the granular iron is decreased considerably, and the iron granules are likely to mutually coalesce. To address such a problem, Patent Literature 3 proposes that the temperature of the cooling water in a pit is maintained at 68°C or lower by regulating the cooling-water flow of secondary cooling water, thereby being able to suppress coalescing of the granular iron accumulated in the pit.

### Citation List

#### Patent Literatures

#### **[0007]**

PTL 1: Japanese Unexamined Patent Application Publication No. 2018-115363

PTL 2: Japanese Examined Patent Application Publication No. 52-20948

PTL 3: Japanese Unexamined Patent Application Publication No. 9-20902

### Summary of Invention

#### Technical Problem

**[0008]** A considerably large-sized cooling water tank is required for cooling the granular iron in view of the fact that, when the granular iron is manufactured from molten pig iron, liquid drops of the molten pig iron horizontally spread to some extent and in view of an installation space for a conveyance device provided for the solidified granular iron. The cooling water tank has a discharge outlet through which the cooling water is supplied and a drain outlet through which the cooling water increased in temperature is conveyed to a cooling facility, thereby allowing the cooling water to circulate between the cooling water

tank and the cooling facility.

[0009] However, it is not easily controllable to spread the cold cooling water throughout the large cooling water tank. Although maintaining the cooling water inside the pit at a temperature of 68°C or lower by regulating the cooling-water flow of the secondary cooling water is described in Patent Literature 3, no method for controlling a flow inside the cooling water tank is described, and, depending on the flow of the cooling water, a stagnation region may be generated inside the cooling water tank. Due to stagnation of the warm cooling water that has been used to cool the granular iron in the stagnation region, a region having a high water temperature may thereby be formed locally. When the granular iron in large amount is dropped into the region having a high water temperature, the film boiling state is maintained for a long time, and the granular iron is failed to be cooled sufficiently; thus, the iron granules are mutually fused to coalesce. Such mutual coalescence of the iron granules increases the amount of the iron granules whose size is large enough to be hardly conveyed; thus, the conveyance of the granular iron becomes difficult. In addition, there is a problem that inclusion of the cooling water occurring when the iron granules mutually coalesce becomes a cause of steam explosion.

[0010] The present invention has been made to solve the above-described problems, and an object thereof is to provide a granular iron manufacturing apparatus and a granular iron manufacturing method that are capable of suppressing mutual coalescence of granular iron by cooling molten iron efficiently.

#### Solution to Problem

[0011] The gist of the present invention capable of solving the above-described problems is as follows.

[1] A granular iron manufacturing apparatus including a granulation device configured to break up molten iron into a liquid drop and a cooling water tank configured to cool the liquid drop by causing the liquid drop to fall into cooling water, the granular iron manufacturing apparatus including: a water-flow controlling container that is provided inside the cooling water tank and whose upper and lower ends are open; and a cooling water pipe group configured to supply cooling water into the water-flow controlling container, in which the water-flow controlling container includes a partition cylindrical body including an inclined surface inclined such that a horizontal cross-sectional area decreases toward a lower side and a duct cylindrical body connected to a lower portion of the partition cylindrical body, the cooling water pipe group includes an upper-level cooling water pipe group and a middle-level cooling water pipe group that are connected to the partition cylindrical body and a lower-level cooling water pipe group connected to the duct cylindrical body, the upper-

level cooling water pipe group is connected to an upper level, of an inclined surface, including an upper end of the partition cylindrical body and generates, with cooling water supplied from the upper-level cooling water pipe group, a cooling-water flow from an upper side to the lower side along an inclined surface, the middle-level cooling water pipe group is connected horizontally to a middle level of an inclined surface of the partition cylindrical body toward a cylindrical core of the partition cylindrical body and generates, with cooling water supplied from the middle-level cooling water pipe group, a first circulating flow including flows moving toward the cylindrical core of the partition cylindrical body, merging at the cylindrical core, and moving upward, the first circulating flow being accompanied by the cooling-water flow from the upper side to the lower side along an inclined surface and circulating inside the partition cylindrical body, and the lower-level cooling water pipe group is connected to a side surface of the duct cylindrical body and generates, with cooling water supplied from the lower-level cooling water pipe group and drainage water from the partition cylindrical body, a second circulating flow circulating inside the duct cylindrical body.

[2] The granular iron manufacturing apparatus according to the item [1], further including

a conveyance device provided below the water-flow controlling container and configured to convey granular iron cooled inside the water-flow controlling container to an outside of the cooling water tank.

[3] The granular iron manufacturing apparatus according to the item [1] or [2], further including a control device configured to control a cooling water flow supplied from the cooling water pipe group into the water-flow controlling container, in which the control device controls such that the cooling water flow supplied from the cooling water pipe group is decreased in an order from the middle-level cooling water pipe group, the upper-level cooling water pipe group, and the lower-level cooling water pipe group.

[4] The granular iron manufacturing apparatus according to any one of the items [1] to [3], in which a protrusion covering an upper side of a connection portion of the upper-level cooling water pipe group and/or the middle-level cooling water pipe group connected to the inclined surface is provided.

[5] The granular iron manufacturing apparatus according to the item [4], in which a sectional shape of the protrusion is an inverted V shape or an inverted U shape becoming wider from the upper side toward the lower side.

[6] The granular iron manufacturing apparatus according to any one of the items [1] to [5], in which a protective cover covering an upper side of a connec-

tion portion of the upper-level cooling water pipe group connected to the inclined surface is provided, and an upper end portion of the protective cover is closed.

[7] The granular iron manufacturing apparatus according to the item [6], in which a sectional shape of the protective cover is a semicircular shape or a semielliptical shape becoming wider from the upper side toward the lower side.

[8] A granular iron manufacturing method using the granular iron manufacturing apparatus according to any one of the items [1] to [7], the middle-level cooling water pipe group, the upper-level cooling water pipe group, and the lower-level cooling water pipe group being decreased in cooling water flow supplied from the cooling water pipe group in this order.

#### Advantageous Effects of Invention

**[0012]** In the granular iron manufacturing apparatus of the present invention, the first circulating flow of the cooling water from the lower side toward the upper side is generated inside the partition cylindrical body, the second circulating flow of the cooling water from the lower side toward the upper side is further generated inside the duct cylindrical body, and the circulating flows cool the granular iron. Thus, the cooling efficiency of the granular iron inside the partition cylindrical body is enhanced, and the iron granules are suppressed from being mutually fused to coalesce during a cooling time of the granular iron. Moreover, by enhancing the cooling efficiency of the granular iron, a more compact apparatus can be realized with the same cooling capacity for the granular iron, and the apparatus can manufacture more granular iron with the same size.

#### Brief Description of Drawings

##### **[0013]**

[Fig. 1] Fig. 1 is a schematic sectional view of a granular iron manufacturing apparatus according to the present embodiment.

[Fig. 2] Fig. 2 is a schematic sectional view of a portion of a water-flow controlling container to which a cooling water pipe group is connected.

[Fig. 3] Fig. 3 is a schematic sectional view illustrating circulating flows generated inside a partition cylindrical body and a duct cylindrical body.

[Fig. 4] Fig. 4 is a schematic sectional view of another water-flow controlling container used for the granular iron manufacturing apparatus according to the present embodiment.

[Fig. 5] Fig. 5 is a schematic view of a water supply inlet provided with a protrusion when viewed horizontally.

[Fig. 6] Fig. 6 is a schematic sectional view of another water-flow controlling container used for the granular

iron manufacturing apparatus according to the present embodiment.

[Fig. 7] Fig. 7 is a schematic view of the water supply inlet provided with a protective cover when viewed horizontally.

[Fig. 8] Fig. 8 illustrates simulation conditions of Inventive Example 1 and Inventive Example 2.

[Fig. 9] Fig. 9 illustrates simulation conditions of Comparative Example 1 and Comparative Example 2.

[Fig. 10] Fig. 10 illustrates simulation results of Inventive Example 1 and Inventive Example 2.

[Fig. 11] Fig. 11 is a schematic perspective view illustrating a water flow of the cooling water supplied from a cooling water pipe group in Inventive Example 1.

[Fig. 12] Fig. 12 illustrates simulation results of Comparative Example 1 and Comparative Example 2.

[Fig. 13] Fig. 13 illustrates a confirmation result of presence or absence of the entry of granular iron into the water supply inlet.

#### Description of Embodiment

**[0014]** Hereinafter, the present invention will be described through an embodiment. Fig. 1 is a schematic sectional view of a granular iron manufacturing apparatus 70 according to the present embodiment. The granular iron manufacturing apparatus 70 is an apparatus configured to manufacture granular iron that is a granular iron material by cooling and solidifying molten iron in form of liquid drops, such as molten pig iron or molten steel. The granular iron manufacturing apparatus 70 includes a granulation device 10 configured to break up molten iron into liquid drops, a cooling water tank 20, a water-flow controlling container 30, a cooling water pipe group 40, and a conveyance device 50.

**[0015]** The granulation device 10 includes a tundish 12 (such as a molten pig iron tub) containing molten iron 60 and provided with a nozzle 16, at a bottom portion, for discharging the molten iron, and the granulation device 10 also includes a molten-iron receiving board 14 against which a liquid column 62 of the molten iron that is discharged through the nozzle 16 and flows down is caused to hit. The molten-iron receiving board 14 is constituted by a disk-shaped refractory material and is supported by a support body 18. The liquid column 62 of the molten iron flowing down from the nozzle 16 hits against the molten-iron receiving board 14, and liquid drops 64 of the molten iron 60 scatter therearound.

**[0016]** When the liquid drops 64 of the molten iron 60 are increased in size, solidification takes time due to increase in heat capacity, and the drops of the molten iron 60, while maintaining a high temperature, are mutually fused to coalesce into a large body inside the water-flow controlling container 30; thus, there may be difficulty in conveyance thereof. For this reason, the granulation device 10 preferably forms the liquid drops 64 such that

the maximum length of granular iron 66 after cooling of the molten iron 60 is 50 mm or less. The molten iron 60 is broken up into the liquid drops 64 at the granulation device 10 and falls into cooling water 24. Moreover, in the granulation device 10, a flow-down amount of the molten iron 60 from the tundish 12 is controlled such that the liquid drops 64 fall into a region where the water-flow controlling container 30 is provided.

**[0017]** The cooling water tank 20 contains the cooling water 24 and the water-flow controlling container 30. The water-flow controlling container 30 is installed in the cooling water 24 contained in the cooling water tank 20. The cooling water 24 contained in the cooling water tank 20 may include the cooling water 24 drained from the water-flow controlling container 30. The cooling water 24 contained in the cooling water tank 20 is drained through a drain outlet 22 by a flow equal to the supplied cooling water flow such that a surface of the cooling water 24 in the cooling water tank 20 is maintained at a constant level. Note that the cooling water tank 20 having a large capacity facilitates the control of the surface of the cooling water and enables the granular iron manufacturing apparatus 70 to stably manufacture the granular iron.

**[0018]** The water-flow controlling container 30 is provided in the cooling water tank 20 at a position at which the water-flow controlling container 30 receives the molten iron broken up into the liquid drops at the granulation device 10. The water-flow controlling container 30 cools and solidifies the liquid drops into the granular iron 66 by using the cooling water 24 contained therein.

**[0019]** The water-flow controlling container 30 includes a partition cylindrical body 32 including an inclined surface 34 inclined such that a horizontal cross-sectional area decreases toward the lower side and a duct cylindrical body 35 connected to a lower portion of the partition cylindrical body 32. The partition cylindrical body 32 has, in an upper end portion, a drop opening 33 for receiving the liquid drops 64, and the duct cylindrical body 35 has, in a lower end portion, a discharge outlet 36 for discharging the granular iron. That is, the upper and lower ends of the water-flow controlling container 30 are open. The outer-side shape of the water-flow controlling container 30 is not particularly limited as long as the inclined surface 34 is formed on the inner side of the water-flow controlling container 30. The inclination angle of the inclined surface 34 is preferably within a range of 40 to 60° in view of, for example, prevention of the build-up of the granular iron 66. In addition, as in Fig. 1, the example without a circular cylindrical portion on the upper end side of the water-flow controlling container 30 is given, but the circular cylindrical portion may be provided on the upper end side of the water-flow controlling container 30.

**[0020]** In the present embodiment, a cooling region A is defined as a cooling region, for the granular iron 66, formed by the water-flow controlling container 30. The reason for providing the cooling region A formed by the water-flow controlling container 30 as described above is to obtain the following two effects.

(1) The granular iron 66 can be cooled efficiently by introducing the cooling water 24 into the cooling region A in a concentrated manner.

(2) The granular iron 66 can be easily collected because the granular iron 66 formed inside the partition cylindrical body 32 is collected in one place due to the inclined surface 34.

**[0021]** The cooling water pipe group 40 is a group of water pipes allowing the cooling water 24 cooled to 0°C or higher and 35°C or lower by a cooling facility such as a heat exchanger or a cooling tower, which is not illustrated, to pass therethrough. When the cooling water 24 is supplied from the cooling water pipe group 40 into the partition cylindrical body 32 of the water-flow controlling container 30, the cooling water 24 has a disposition to flow to the upper side where the opening is large. Thus, when the cooling water is supplied from the lower side of the partition cylindrical body 32 toward a cylindrical core, flows of the cooling water merge at the cylindrical core inside the partition cylindrical body 32 and move upward. On the other hand, when the cooling water is supplied from the upper side to the lower side of the partition cylindrical body 32 along the inclined surface 34, the flows of the cooling water 24 that have moved upward after merging at the cylindrical core inside the partition cylindrical body 32 do not move out into the cooling water tank 20 through the drop opening 33 of the partition cylindrical body 32 and spread toward a circumferential direction near the drop opening 33; thus, a first circulating flow accompanied by the cooling-water flow moving downward along the inclined surface 34 of the partition cylindrical body 32 is generated. By generating the first circulating flow, the granular iron 66 can be cooled by a counterflow, and a stagnation region inside the partition cylindrical body 32 can be reduced. The cooling water pipe group 40 includes an upper-level cooling water pipe group 44 and a middle-level cooling water pipe group 46 that are connected to the partition cylindrical body and a lower-level cooling water pipe group 48 connected to the duct cylindrical body 35.

**[0022]** The middle-level cooling water pipe group 46 is connected horizontally to a middle level, of the inclined surface 34, in a range from the center of the partition cylindrical body 32 in an up-down direction to a level 650 mm lower than the center, toward the cylindrical core of the partition cylindrical body 32. When the cooling water 24 is supplied from the middle-level cooling water pipe group 46 into the partition cylindrical body 32, flows of the cooling water 24 move toward the cylindrical core of the partition cylindrical body 32, merge at the cylindrical core, and move upward. The flows of the cooling water 24 that have moved upward after merging at the cylindrical core spread in the circumferential direction at the upper end of the partition cylindrical body 32 and flow downward along the inclined surface 34, and the first circulating flow is thus generated. The cooling water 24 supplied from the middle-level cooling water pipe group 46 forms part of the

first circulating flow.

**[0023]** The cooling water flow supplied from the middle-level cooling water pipe group 46 is preferably 1500 m<sup>3</sup>/h or more and 3900 m<sup>3</sup>/h or less. The cooling water flow less than 1500 m<sup>3</sup>/h is not preferable because a strong and stable upward flow is hardly generated at the cylindrical core of the partition cylindrical body 32. In addition, the cooling water flow more than 3900 m<sup>3</sup>/h is not preferable because some of the cooling water 24 deviates from the first circulating flow and flows into the cooling water tank 20 through the drop opening 33 of the partition cylindrical body 32.

**[0024]** The flow velocity of the cooling water 24 supplied from the middle-level cooling water pipe group 46 is preferably 1.8 m/s or more and 2.2 m/s or less. The cooling water 24 supplied from the middle-level cooling water pipe group 46 at a flow velocity slower than 1.8 m/s is not preferable because the cooling water 24 decelerates before reaching the cylindrical core of the partition cylindrical body 32, and a strong and stable upward flow is thus hardly generated. In addition, the cooling water 24 supplied from the middle-level cooling water pipe group 46 at a flow velocity faster than 2.2 m/s is not preferable because the pressure loss in a cooling water pipe 41 is increased, and a large-scaled water delivery facility such as a pump is thus required.

**[0025]** The upper-level cooling water pipe group 44 is connected to an upper level of the inclined surface 34 including the upper end of the partition cylindrical body 32. The upper-level cooling water pipe group 44 is connected to a water supply jacket 45. The water supply jacket 45 covers an upper-level portion of the partition cylindrical body 32 including a slit 42 having a predetermined gap in an upper-end peripheral edge of the partition cylindrical body 32 and water supply inlets 43 provided in the inclined surface 34 at the upper level of the partition cylindrical body 32, and the water supply jacket 45 supplies the cooling water into the slit 42 and the water supply inlets 43. The upper-level cooling water pipe group 44 is connected to a portion of the inclined surface 34, including the upper end of the partition cylindrical body 32, in a range from the upper end of the partition cylindrical body 32 to a level 1000 m lower than the upper end of the partition cylindrical body 32.

**[0026]** The flow velocity of the cooling water 24 supplied through each of the slit 42 and the water supply inlets 43 is preferably 0.1 m/s or more and 0.7 m/s or less. When the cooling water 24 is supplied into the partition cylindrical body 32 through each of the slit 42 and the water supply inlets 43 at a flow velocity within this range, the cooling water 24 flows from the upper end of the inclined surface 34 toward the lower side along the inclined surface 34, instead of flowing toward the cylindrical core of the partition cylindrical body 32. Thus, the cooling water 24 supplied from the upper-level cooling water pipe group 44 come to form part of the first circulating flow, thereby stabilizing the first circulating flow. The cooling water flow supplied from the upper-level cooling

water pipe group 44 is preferably 700 m<sup>3</sup>/h or more and 3000 m<sup>3</sup>/h or less. The cooling water flow supplied from the upper-level cooling water pipe group 44 less than 700 m<sup>3</sup>/h is not preferable because the first circulating flow may be failed to be stabilized. In addition, the cooling water flow supplied from the upper-level cooling water pipe group 44 more than 3000 m<sup>3</sup>/h is not preferable because the effect of stabilizing the first circulating flow is saturated, the cooling water moves downward along the inclined surface 34 without contributing to cool the granular iron 66 and is just drained through the drain outlet 22 in a lower end of the partition cylindrical body 32. In addition, the distribution ratio of the cooling water flow supplied through the slit 42 to the cooling water flow supplied through the water supply inlets 43 is preferably 6:4.

**[0027]** In the lower-level cooling water pipe group 48, at least one pair of water pipes is connected horizontally to a side surface of the duct cylindrical body 35 toward a cylindrical core of the duct cylindrical body 35 while the water pipes facing each other. When the cooling water 24 is supplied from the lower-level cooling water pipe group 48 into the duct cylindrical body 35, flows of the cooling water 24 move toward the cylindrical core of the duct cylindrical body 35, merge at the cylindrical core, and move upward, and a second circulating flow circulating inside the duct cylindrical body 35 is thus generated.

**[0028]** The cooling water flow supplied from the lower-level cooling water pipe group 48 is preferably 250 m<sup>3</sup>/h or more and 750 m<sup>3</sup>/h or less. The cooling water flow supplied from the lower-level cooling water pipe group 48 less than 250 m<sup>3</sup>/h is not preferable because the second circulating flow inside the duct cylindrical body 35 is hardly generated, and a stagnation region having a high water temperature may be generated. In addition, the cooling water flow supplied from the lower-level cooling water pipe group 48 more than 750 m<sup>3</sup>/h is not preferable because drainage from the lower end of the partition cylindrical body 32 is impeded.

**[0029]** The flow velocity of the cooling water 24 supplied from the lower-level cooling water pipe group 48 is preferably 0.5 m/s or more and 1.0 m/s or less. The cooling water 24 supplied into the duct cylindrical body 35 at a flow velocity slower than 0.5 m/s is not preferable because the effect of stirring the inside of the duct cylindrical body 35 is reduced. In addition, the cooling water 24 supplied into the duct cylindrical body 35 at a flow velocity faster than 1.0 m/s is not preferable because the amount of leaking water from a gap between the lower end of the duct cylindrical body 35 and the conveyance device 50 is increased.

**[0030]** Fig. 2 is a schematic sectional view of a portion of the water-flow controlling container 30 to which the cooling water pipe group is connected. Fig. 2(a) is a schematic sectional view of a portion of the water-flow controlling container 30 to which the upper-level cooling water pipe group 44 is connected, and Fig. 2(b) is a schematic sectional view of a portion of the water-flow

controlling container 30 to which the middle-level cooling water pipe group 46 is connected. Fig. 2(c) is a schematic sectional view of a portion of the water-flow controlling container 30 to which the lower-level cooling water pipe group 48 is connected.

**[0031]** As Fig. 2(a) illustrates, the upper-level cooling water pipe group 44 is constituted by two cooling water pipes 41. The cooling water 24 is supplied from the two cooling water pipes 41 to the water supply jacket 45 and is distributed, in the water supply jacket 45, into the slit 42 having an annular shape and 16 water supply inlets 43 radially arranged in the inclined surface 34 of the partition cylindrical body 32. The cooling water 24 is supplied into the partition cylindrical body 32 through the annular slit 42 and the 16 water supply inlets 43. The middle-level cooling water pipe group 46 is constituted by four cooling water pipes 41 each disposed horizontally toward the cylindrical core of the partition cylindrical body 32. The cooling water 24 is supplied into the partition cylindrical body 32 from the four cooling water pipes 41. The lower-level cooling water pipe group 48 is constituted by four cooling water pipes 41. Two of the four cooling water pipes 41 are each disposed horizontally toward the cylindrical core of the duct cylindrical body 35 while facing each other, and the other two cooling water pipes 41 are disposed on a side surface of the duct cylindrical body. The cooling water 24 is supplied from the four cooling water pipes 41 into the duct cylindrical body 35. As described above, in the granular iron manufacturing apparatus 70 according to the present embodiment, the cooling water is supplied into the partition cylindrical body 32 and the duct cylindrical body 35 by using in total 10 cooling water pipes 41. Note that, although the sectional shape of the duct cylindrical body 35 is a quadrilateral in the example illustrated in Fig. 2, this is not the only option, and the sectional shape of the duct cylindrical body 35 may be a circle.

**[0032]** Fig. 3 is a schematic sectional view illustrating circulating flows generated inside the partition cylindrical body 32 and the duct cylindrical body 35. A first circulating flow B1 is a circulating flow circulating inside the partition cylindrical body 32. Flows of the cooling water 24 supplied from the middle-level cooling water pipe group 46 merge at cylindrical core to thus generate a strong upward flow. Near the drop opening 33, the strong upward flow spreads toward a peripheral edge portion. The water flows that have moved to the peripheral edge portion become downward flows moving downward along the inclined surface 34. The downward flows merge with the cooling-water flows from the slit 42 and the water supply inlets 43, move toward the lower side along the inclined surface 34 due to the regulating action of the cooling-water flows, and are discharged from the lower end connected to the duct cylindrical body 35. The first circulating flow B1 inside the partition cylindrical body 32 can maintain the water temperature in a region, of the cooling region A, from the middle level to the upper level at a suitable water temperature of about 50°C. In addition,

the strong upward flow generated at a cylindrical core part of the partition cylindrical body 32 is a counterflow relative to the granular iron 66 dropped through the drop opening 33 and moving downward, thereby being able to cool the granular iron 66 with a high degree of cooling efficiency.

**[0033]** A second circulating flow B2 is a circulating flow generated inside the duct cylindrical body 35. The drainage water from the lower end of the partition cylindrical body 32 merges with a discharge flow of the low-temperature water from the lower-level cooling water pipe group 48 and is stirred, and a circulating flow is thereby generated inside the duct cylindrical body 35. Thus, the granular iron collected by the partition cylindrical body 32 can be cooled efficiently.

**[0034]** As described above, by generating the first circulating flow B1 inside the partition cylindrical body 32 and the second circulating flow B2 inside the duct cylindrical body 35, the cooling water inside each of the partition cylindrical body 32 and the duct cylindrical body 35 is stirred, and a stagnation region inside each of the partition cylindrical body 32 and the duct cylindrical body 35 can be suppressed from being generated. Thus, a local temperature rise of the cooling water 24 inside each of the partition cylindrical body 32 and the duct cylindrical body 35 is suppressed, and the granular iron 66 can be cooled efficiently. As a result, fusion and coalescence of the granular iron 66 due to insufficient cooling can be suppressed.

**[0035]** Since the upward flow generated at the cylindrical core of the partition cylindrical body 32 is a cooling-water flow against the granular iron 66 dropped through the drop opening 33 and falling, a high degree of cooling efficiency can be obtained. To form the upward flow appropriately, the total cooling water flow supplied from the middle-level cooling water pipe group 46 is preferably larger than the total cooling water flow supplied from the upper-level cooling water pipe group 44.

**[0036]** In addition, flows of the cooling water supplied from the upper-level cooling water pipe group 44 connected to the upper level of the inclined surface 34 of the partition cylindrical body 32 move downward along the inclined surface 34 and thus collide with the discharge flows from the middle-level cooling water pipe group 46 connected to the middle level of the inclined surface 34 of the partition cylindrical body 32. Thus, if the cooling water flow supplied from the upper-level cooling water pipe group 44 is larger than the cooling water flow supplied from the middle-level cooling water pipe group 46, there is concern that the water flows of the cooling water from the upper-level cooling water pipe group 44 may weaken the flows of the water discharged from the middle-level cooling water pipe group 46, and the first circulating flow B1 may hardly be formed. Thus, the total cooling water flow supplied from the middle-level cooling water pipe group 46 is preferably larger than the total cooling water flow supplied from the upper-level cooling water pipe group 44. Moreover, the total cooling water flow supplied

from the middle-level cooling water pipe group 46 is more preferably about four times the total cooling water flow supplied from the upper-level cooling water pipe group 44.

**[0037]** The total cooling water flow supplied from the lower-level cooling water pipe group 48 connected to the duct cylindrical body 35 is preferably smaller than the cooling water flow supplied from the upper-level cooling water pipe group 44. If the total cooling water flow supplied from the lower-level cooling water pipe group 48 is larger than the total cooling water flow supplied from the upper-level cooling water pipe group 44, there is concern that the drainage from the lower end of the partition cylindrical body 32 to the duct cylindrical body 35 may be impeded, and the temperature inside the partition cylindrical body 32 may be increased on the contrary. Thus, the total cooling water flow supplied from the lower-level cooling water pipe group 48 is preferably smaller than the total cooling water flow supplied from the upper-level cooling water pipe group 44. Moreover, the total cooling water flow supplied from the lower-level cooling water pipe group 48 is more preferably about one-half the total cooling water flow supplied from the upper-level cooling water pipe group 44.

**[0038]** To generate the first circulating flow B1 appropriately and to suppress the temperature inside the partition cylindrical body 32 from being increased on the contrary, the total cooling water flow supplied from each of the cooling water pipe groups is preferably decreased in the order from the middle-level cooling water pipe group 46, the upper-level cooling water pipe group 44, and the lower-level cooling water pipe group 48. Since controlling the total cooling water flow supplied from each of the cooling water pipe groups as described above is preferable, the granular iron manufacturing apparatus 70 according to the present embodiment preferably further includes a control device configured to control the total cooling water flow supplied from each of the upper-level cooling water pipe group 44, the middle-level cooling water pipe group 46, and the lower-level cooling water pipe group 48. The control device is configured by using a general-purpose computer and controls the supply water flow of the cooling water 24 delivered to each of the cooling water pipe groups by controlling a cooling facility such as a heat exchanger or a cooling tower, which is not illustrated.

**[0039]** In addition, the granular iron 66 that has been cooled inside the water-flow controlling container 30 is discharged through the discharge outlet 36 provided in a lower portion of the water-flow controlling container 30. The discharged granular iron 66 is conveyed outside the cooling water tank 20 by the conveyance device 50 such as a conveyor belt. The conveyance device 50 is not limited to the conveyor belt and may be other conveyance devices as long as the devices can convey the granular iron 66 outside the cooling water tank 20. However, a mesh conveyor preferably serves as the conveyance device 50 so as not to carry the cooling water 24 outside

the cooling water tank 20.

**[0040]** Fig. 4 is a schematic sectional view of another water-flow controlling container 80 used for the granular iron manufacturing apparatus according to the present embodiment. In the water-flow controlling container 80 illustrated in Fig. 4, the same constituents as those in the water-flow controlling container 30 illustrated in Fig. 1 are denoted by the same reference numbers, and the description thereof will be omitted. The water-flow controlling container 80 illustrated in Fig. 4 differs from the water-flow controlling container 30 in illustrated Fig. 1 in that a protrusion 90 is provided.

**[0041]** When the water supply inlet 43 through which the cooling water 24 is supplied is provided in the inclined surface 34 of the partition cylindrical body 32, there is concern that the granular iron 66 falling along the inclined surface 34 may enter the water supply inlet 43 and close the water supply inlet 43. Thus, the protrusion 90 covering the upper side of the water supply inlet 43 and/or a connection portion of the middle-level cooling water pipe group 46 to the inclined surface is preferably provided. Here, "covering the upper side of the water supply inlet 43 and the connection portion of the middle-level cooling water pipe group 46" means providing the protrusion 90 up to a position at which the protrusion 90 hides the water supply inlet 43 and the connection portion of the middle-level cooling water pipe group 46 in top view. In addition, the protrusion 90 preferably protrudes horizontally from the inclined surface 34 toward the inside of the partition cylindrical body 32 so as not to impede the flow of the supplied cooling water 24.

**[0042]** Fig. 5 is a schematic view of the water supply inlet 43 provided with a protrusion when viewed horizontally. Fig. 5(a) illustrates the protrusion 90 having an inverted V shape, and Fig. 5(b) illustrates a protrusion 91 having an inverted U shape. As Fig. 5(a) illustrates, the sectional shape of the protrusion 90 is preferably the inverted V shape protruding upward and inclined so as to become wider toward the lower side. By forming the sectional shape of the protrusion 90 into the inverted V shape, the granular iron 66 can be suppressed from entering the water supply inlet 43 while being suppressed from accumulating on an upper surface of the protrusion 90.

**[0043]** The protrusion 91 having an inverted U-shaped section may be provided instead of the protrusion 90. By providing the protrusion 91 having the inverted U-shaped section as described above, the granular iron 66 can be suppressed from entering the water supply inlet 43 while being suppressed from accumulating on an upper surface of the protrusion 91.

**[0044]** Fig. 6 is a schematic sectional view of another water-flow controlling container 82 used for the granular iron manufacturing apparatus according to the present embodiment. In the water-flow controlling container 82 illustrated in Fig. 6, the same constituents as those in the water-flow controlling container 80 illustrated in Fig. 4 are denoted by the same reference numbers, and the de-



scription thereof will be omitted. The water-flow controlling container 82 illustrated in Fig. 6 differs from the water-flow controlling container 80 illustrated in Fig. 4 in that a protective cover 92 is provided.

[0045] As described above, when the water supply inlet 43 is provided, there is concern that the granular iron 66 falling along the inclined surface 34 may enter the water supply inlet 43 and close the water supply inlet 43. In particular, the granular iron 66 at the upper level of the partition cylindrical body 32 is still in a molten state and is thereby hardly removed when adhering to an inner side of the water supply inlet 43. Thus, it is more preferable to provide the protective cover 92 covering the upper side of the water supply inlet 43. Here, "covering the upper side of the water supply inlet 43" means providing the protective cover 92 up to a position at which the protective cover 92 hides the water supply inlet 43 in top view. In addition, the protective cover 92 is preferably provided at a position at which the protective cover 92 does not hide the water supply inlet 43 when viewed horizontally so as not to impede the flow of the cooling water 24 supplied through the water supply inlet 43. Moreover, the protective cover 92 also covers a portion of the inclined surface 34 above the water supply inlet 43 along an inclination direction of the inclined surface 34. An upper end portion of the protective cover 92 preferably has a structure that is closed so as to prevent the scattering liquid drops 64 from entering the inside of the protective cover 92, and the inclination angle of the protective cover 92 is preferably equal to that of the inclined surface 34.

[0046] Fig. 7 is a schematic view of the water supply inlet 43 provided with the protective cover 92 when viewed horizontally. As Fig. 7 illustrates, the sectional shape of the protective cover 92 is preferably a semicircular shape or a semielliptical shape becoming wider toward the lower side. By forming the sectional shape of the protective cover 92 into the semicircular shape or the semielliptical shape, the granular iron 66 can be suppressed from entering the water supply inlet 43 while being suppressed from accumulating on an upper surface of the protective cover 92.

[0047] Note that the example in which each of the water-flow controlling containers 80 and 82 is provided with one of the protrusion 90 and the protective cover 92 for the water supply inlet 43 is given but is not the only option, and the protrusion 90 and the protective cover 92 may be provided for the water supply inlet 43. Even with such a configuration, the granular iron 66 can be suppressed from entering the water supply inlet 43.

[0048] As described above, the granular iron manufacturing apparatus 70 according to the present embodiment manufactures the granular iron 66 from the molten iron 60 by generating the first circulating flow B1 of the cooling water 24 from the lower side toward the upper side inside the partition cylindrical body 32, by further generating the second circulating flow B2 of the cooling water 24 from the lower side toward the upper side inside the duct cylindrical body 35, and by cooling the granular

iron 66 by the two circulating flows. The first circulating flow B1 is a counterflow relative to the direction where the granular iron 66 moves downward, and thus cools the granular iron 66 efficiently. Moreover, the circulating flows B1 and B2 stir the inside of the partition cylindrical body 32 and the inside of the duct cylindrical body 35, and a stagnation region inside each of the partition cylindrical body 32 and the duct cylindrical body 35 is thereby suppressed from being generated. Consequently, the cooling effect of the granular iron is enhanced, and the iron granules are suppressed from being mutually fused to coalesce during a cooling time of the granular iron.

[0049] Next, a result of a simulation conducted for confirming the cooling effect of the granular iron exhibited by the granular iron manufacturing apparatus according to the present embodiment will be described. A cooling water supply model having the same configuration as the water-flow controlling container 30 disposed inside the cooling water tank 20 in Fig. 1 was created, and the water temperature distribution of the cooling water inside the water-flow controlling container and in the vicinity thereof was simulated by using the model. Note that the falling speeds and the heat amounts of the granular iron in the water inside the partition cylindrical body and on the inclined surface were actually measured through experiments conducted in advance, and the position distribution and the amount of generated heat of the granular iron inside each of the partition cylindrical body and the duct cylindrical body were modeled.

[0050] In a simulation result, it has been judged that efficient cooling of the granular iron can be achieved in a case where the temperatures of the cooling water inside the partition cylindrical body, inside the duct cylindrical body, and in the vicinities thereof are 70°C or lower, and, moreover, the granular iron is cooled to 650°C or lower when accumulated on the conveyance device.

[0051] Fig. 8 illustrates simulation conditions of Inventive Example 1 and Inventive Example 2. Fig. 9 illustrates simulation conditions of Comparative Example 1 and Comparative Example 2. Simulations were conducted with the cooling water supply models of Inventive Examples 1 and 2 and Comparative Examples 1 and 2 in which pipe layout, pipe count, the flow rate distribution of the cooling water, and pipe diameter (nominal diameter (A)) were set as in Figs. 8 and 9. Note that the cooling water pipe layout of Inventive Example 1 is the same as the cooling water pipe layout of the water-flow controlling container 30 illustrated in Fig. 2.

[0052] The cooling water pipe layout of Inventive Example 2 is the same as the cooling water pipe layout of Inventive Example 1, except that the number of the cooling water pipes of the upper-level cooling water pipe group connected to the water supply jacket is one, and the number of the water pipes of the lower-level cooling water pipe group connected to the side surface of the duct cylindrical body is one fewer than that of Inventive Example 1. The model of Inventive Example 2 was changed in flow rate distribution of the cooling water as follows.

The total cooling water flow supplied from the middle-level cooling water pipe group was about 40% of that of Inventive Example 1, and the water flow of the cooling water supplied from the upper-level cooling water pipe group was three times that of Inventive Example 1.

**[0053]** In the model of Comparative Example 1, the upper-level cooling water pipe group and the lower-level cooling water pipe group were omitted, and only the middle-level cooling water pipe group supplied the cooling water. The pipe count, the arrangement, the flow rate of the cooling water, and the pipe diameter of Comparative Example 1 were similar to those of Inventive Example 1. The model of Comparative Example 2 was changed in flow rate distribution of the cooling water as follows. The number of the pipes of each of the middle-level cooling water pipe group and the lower-level cooling water pipe group was a half or less of that of Inventive Example 1 to reduce the water flow of the supplied cooling water by half, and the water flow of the cooling water supplied from the upper-level cooling water pipe group was twice that of Inventive Example 1. Two pipes of the middle-level cooling water pipe group were connected to the inclined surface at point-symmetric positions relative to the center of a horizontal section of the partition cylindrical body such that central axes of the cooling water pipes were parallel to each other.

**[0054]** Other simulation conditions common to Inventive Example 1, Inventive Example 2, Comparative Example 1, and Comparative Example 2 are as follows.

- (1)The temperature of the molten pig iron: 1500°C
- (2)The outflow rate of the molten iron from the tundish: 450 ton/h
- (3)The water temperature of the cooling water: 35°C
- (4)The inclination angle of the inclined surface of the partition cylindrical body: 56°
- (5)The diameter of the discharge outlet of the partition cylindrical body:  $\phi 1560$  mm
- (6)The height of the partition cylindrical body: 3300 mm
- (7)The height of the inclined surface of the partition cylindrical body: 3291 mm (incline length: 3970 mm)

**[0055]** Fig. 10 illustrates simulation results of Inventive Example 1 and Inventive Example 2. As given in Inventive Example 1 of Fig. 10, the temperature of the cooling water inside the water-flow controlling container fell within a range of 52 to 69°C, thereby achieving a target temperature of 70°C or less. Further, the temperature of the granular iron when accumulated on the conveyance device was 550°C at the maximum, thereby also achieving a target granular iron temperature of 650°C or less.

**[0056]** Fig. 11 is a schematic perspective view illustrating a water flow of the cooling water supplied from the cooling water pipe group in Inventive Example 1. Fig. 11(a) is a schematic perspective view illustrating a water flow of the cooling water supplied from the upper-level

cooling water pipe group. Fig. 11(b) is a schematic perspective view illustrating a water flow of the cooling water supplied from the middle-level cooling water pipe group. Fig. 11(c) is a schematic perspective view illustrating a water flow of the cooling water supplied from the lower-level cooling water pipe group. As Figs. 11(a) and 11(b) illustrate, it has been confirmed that the first circulating flow was generated inside the partition cylindrical body in Inventive Example. In addition, as in Fig. 11(c), it has been confirmed that the second circulating flow was generated inside the duct cylindrical body in Inventive Example.

**[0057]** Referring again to Fig. 10, in Inventive Example 2, although the cooling water flow from the middle-level cooling water pipe group was reduced to 40%, an upward flow at the cylindrical core was generated. A strong water flow moving downward from the upper-level cooling water pipe group along the inclined surface of the partition cylindrical body was generated particularly on the side where the cooling water pipe was connected to the water supply jacket (on the right side of the paper sheet of the figure), the cooling water was stirred while the first circulating flow was stabilized, the temperature of the cooling water inside the water-flow controlling container was maintained at 70°C or less, and the target temperature of 70°C or less was thus achieved. Further, the temperature of the granular iron when accumulated on the conveyance device was 646°C at the maximum, thereby also achieving the target granular iron temperature of 650°C or less. Note that, in comparison of the temperature of the granular iron when accumulated on the conveyance device between Inventive Example 1 and Inventive Example 2, the temperature of the granular iron in Inventive Example 1, in which the total cooling water flow supplied from the middle-level cooling water pipe group was made larger than the total cooling water flow supplied from the upper-level cooling water pipe group, was about 100°C lower than that of Inventive Example 2. It has been confirmed, from these results, that the granular iron could be cooled with a high degree of cooling efficiency by making the total cooling water flow supplied from the middle-level cooling water pipe group larger than the total cooling water flow supplied from the upper-level cooling water pipe group.

**[0058]** Fig. 12 illustrates simulation results of Comparative Example 1 and Comparative Example 2. As Fig. 12 illustrates, in Comparative Example 1, a large amount of the cooling water was supplied from the middle-level cooling water pipe group, and a strong upward flow was thereby generated. The upward flow stirred the cooling water and maintained the temperature of the cooling water in a center region of the partition cylindrical body at 70°C or less. However, the cooling water was not stirred in an upper region and a lower region of the partition cylindrical body, and the cooling water stagnated in the regions. Thus, the temperature of the granular iron when accumulated on the conveyance device became 652°C and was slightly above the target temperature of

650°C or less.

**[0059]** In Comparative Example 2, the two cooling water pipes of the middle-level cooling water pipe group were connected to the inclined surface of the partition cylindrical body at point-symmetric positions relative to the center of the horizontal section of the partition cylindrical body such that the central axes of the cooling water pipes were parallel to each other. Thus, different from Inventive Example 1 and Comparative Example 1, a strong upward flow in the vicinity of the cylindrical core was not generated, and a swirl flow moving upward while swirling inside the partition cylindrical body was generated instead of the upward flow. The water temperature inside the partition cylindrical body of Comparative Example 2 became lower than that of each of Inventive Example 1 and Comparative Example 1, which proves that the heat of the granular iron was not taken. The temperature of the granular iron when accumulated on the conveyance device became 700°C at the maximum and thus exceeded substantially the target temperature of 650°C or less, and a wide range of granular iron temperature variation from 460°C to 700°C was exhibited. It has been confirmed, from the above simulation results, that the granular iron manufacturing apparatus according to the present embodiment could cool the granular iron efficiently.

**[0060]** Next, regarding the water-flow controlling container 80 illustrated in Fig. 4 and the water-flow controlling container 82 illustrated in Fig. 6, a confirmation result of presence or absence of the entry of the granular iron into the water supply inlet 43 will be described. Fig. 13 illustrates a confirmation result of presence or absence of the entry of granular iron into the water supply inlet 43. The water-flow controlling container 80 illustrated in Fig. 4 is given in Inventive Example 3, and the water-flow controlling container 82 illustrated in Fig. 6 is given in Inventive Example 4.

**[0061]** In Inventive Example 3, since the protrusion 90 covering the upper side of the water supply inlet 43 was provided, the protrusion 90 suppressed the granular iron from entering the water supply inlet 43. Thus, it has been confirmed that the water supply inlet 43 could allow the cooling water 24 to be supplied therethrough without being closed by the granular iron, and the granular iron could be manufactured while being cooled with a high degree of cooling efficiency by using the water-flow controlling container 80.

**[0062]** In Inventive Example 4, since the protective cover 92 covering the upper side of the water supply inlet 43 was provided, the protective cover 92 suppressed the granular iron from entering the water supply inlet 43. Thus, it has been confirmed that the water supply inlet 43 could allow the cooling water 24 to be supplied therethrough without being closed by the granular iron, and the granular iron could be manufactured while being cooled with a high degree of cooling efficiency by using the water-flow controlling container 82.

## Reference Signs List

### [0063]

|    |    |                                       |
|----|----|---------------------------------------|
| 5  | 10 | granulation device                    |
|    | 12 | tundish                               |
|    | 14 | molten-iron receiving board           |
|    | 16 | nozzle                                |
|    | 18 | support body                          |
| 10 | 20 | cooling water tank                    |
|    | 22 | drain outlet                          |
|    | 24 | cooling water                         |
|    | 30 | water-flow controlling container      |
|    | 32 | partition cylindrical body            |
| 15 | 33 | drop opening                          |
|    | 34 | inclined surface                      |
|    | 35 | duct cylindrical body                 |
|    | 36 | discharge outlet                      |
|    | 40 | cooling water pipe group              |
| 20 | 41 | cooling water pipe                    |
|    | 42 | slit                                  |
|    | 43 | water supply inlet                    |
|    | 44 | upper-level cooling water pipe group  |
|    | 45 | water supply jacket                   |
| 25 | 46 | middle-level cooling water pipe group |
|    | 48 | lower-level cooling water pipe group  |
|    | 50 | conveyance device                     |
|    | 60 | molten iron                           |
|    | 62 | liquid column                         |
| 30 | 64 | liquid drop                           |
|    | 66 | granular iron                         |
|    | 70 | granular iron manufacturing apparatus |
|    | 80 | water-flow controlling container      |
|    | 82 | water-flow controlling container      |
| 35 | 90 | protrusion                            |
|    | 91 | protrusion                            |
|    | 92 | protective cover                      |

## Claims

1. A granular iron manufacturing apparatus including a granulation device configured to break up molten iron into a liquid drop and a cooling water tank configured to cool the liquid drop by causing the liquid drop to fall into cooling water, the granular iron manufacturing apparatus comprising:

a water-flow controlling container that is provided inside the cooling water tank and whose upper and lower ends are open; and a cooling water pipe group configured to supply cooling water into the water-flow controlling container, wherein

the water-flow controlling container includes a partition cylindrical body including an inclined surface inclined such that a horizontal cross-sectional area decreases toward a lower side and a duct cylindrical body connected to a lower

portion of the partition cylindrical body,  
 the cooling water pipe group includes an upper-  
 level cooling water pipe group and a middle-  
 level cooling water pipe group that are con-  
 nected to the partition cylindrical body and a  
 lower-level cooling water pipe group connected  
 to the duct cylindrical body,  
 the upper-level cooling water pipe group is con-  
 nected to an upper level, of an inclined surface,  
 including an upper end of the partition cylindrical  
 body and generates, with cooling water supplied  
 from the upper-level cooling water pipe group, a  
 cooling-water flow from an upper side to the  
 lower side along an inclined surface,  
 the middle-level cooling water pipe group is  
 connected horizontally to a middle level of an  
 inclined surface of the partition cylindrical body  
 toward a cylindrical core of the partition cylind-  
 rical body and generates, with cooling water  
 supplied from the middle-level cooling water  
 pipe group, a first circulating flow including flows  
 moving toward the cylindrical core of the parti-  
 tion cylindrical body, merging at the cylindrical  
 core, and moving upward, the first circulating  
 flow being accompanied by the cooling-water  
 flow from the upper side to the lower side along  
 an inclined surface and circulating inside the  
 partition cylindrical body, and  
 the lower-level cooling water pipe group is con-  
 nected to a side surface of the duct cylindrical  
 body and generates, with cooling water supplied  
 from the lower-level cooling water pipe group  
 and drainage water from the partition cylindrical  
 body, a second circulating flow circulating inside  
 the duct cylindrical body.

2. The granular iron manufacturing apparatus accord-  
 ing to Claim 1, further comprising

a conveyance device provided below the water-  
 flow controlling container and  
 configured to convey granular iron cooled inside  
 the water-flow controlling container to an outside  
 of the cooling water tank.

3. The granular iron manufacturing apparatus accord-  
 ing to Claim 1 or 2, further comprising  
 a control device configured to control a cooling water  
 flow supplied from the cooling water pipe group into  
 the water-flow controlling container, wherein the  
 control device controls such that the cooling water  
 flow supplied from the cooling water pipe group is  
 decreased in an order from the middle-level cooling  
 water pipe group, the upper-level cooling water pipe  
 group, and the lower-level cooling water pipe group.
4. The granular iron manufacturing apparatus accord-  
 ing to any one of Claims 1 to 3, wherein

a protrusion covering an upper side of a connection  
 portion of the upper-level cooling water pipe group  
 and/or the middle-level cooling water pipe group  
 connected to the inclined surface is provided.

5. The granular iron manufacturing apparatus accord-  
 ing to Claim 4, wherein  
 a sectional shape of the protrusion is an inverted V  
 shape or an inverted U shape becoming wider from  
 the upper side toward the lower side.
6. The granular iron manufacturing apparatus accord-  
 ing to any one of Claims 1 to 5, wherein  
 a protective cover covering an upper side of a con-  
 nection portion of the upper-level cooling water pipe  
 group connected to the inclined surface is provided,  
 and an upper end portion of the protective cover is  
 closed.
7. The granular iron manufacturing apparatus accord-  
 ing to Claim 6, wherein  
 a sectional shape of the protective cover is a semi-  
 circular shape or a semielliptical shape becoming  
 wider from the upper side toward the lower side.
8. A granular iron manufacturing method using the  
 granular iron manufacturing apparatus according  
 to any one of Claims 1 to 7, the middle-level cooling  
 water pipe group, the upper-level cooling water pipe  
 group, and the lower-level cooling water pipe group  
 being decreased in cooling water flow supplied from  
 the cooling water pipe group in this order.

FIG. 1

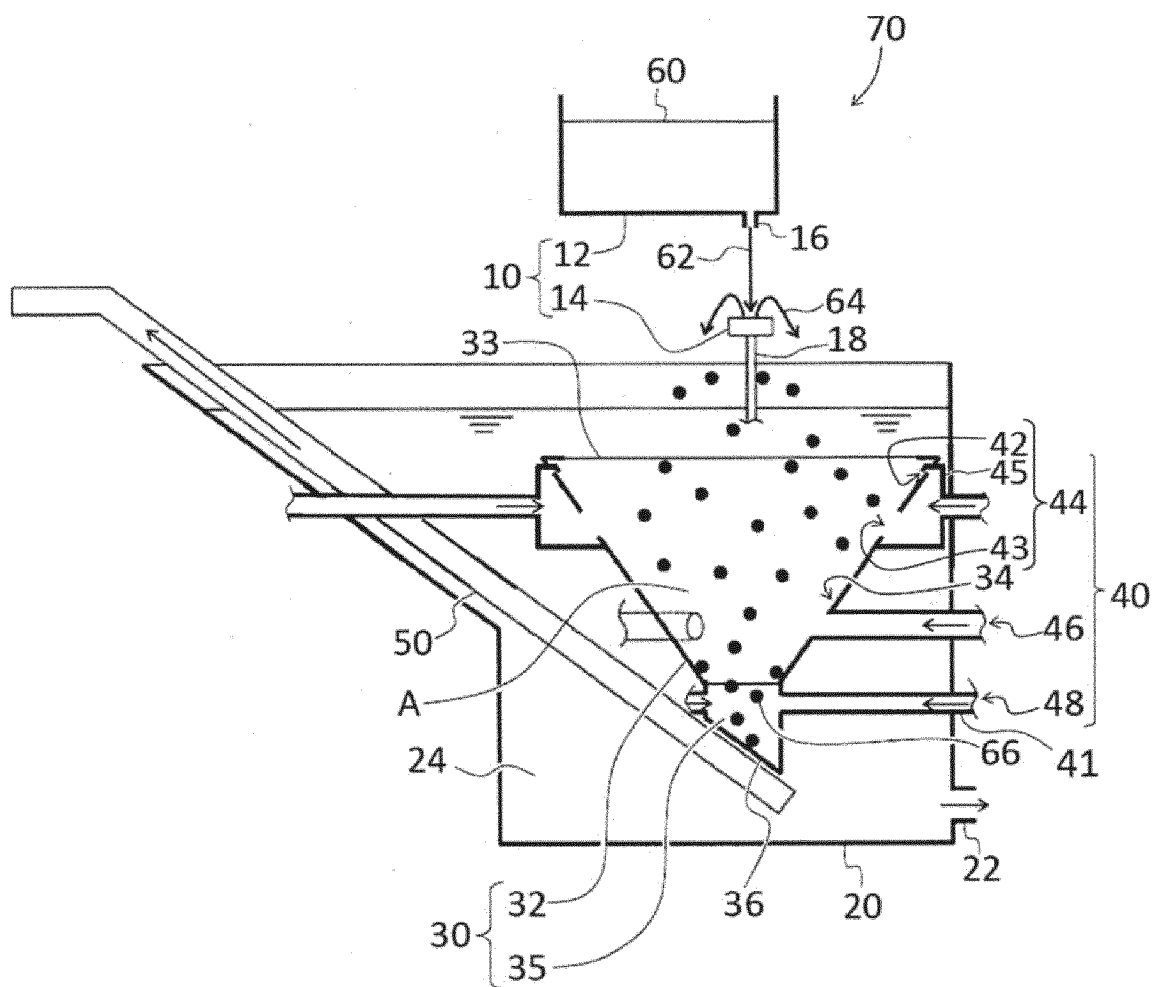


FIG. 2

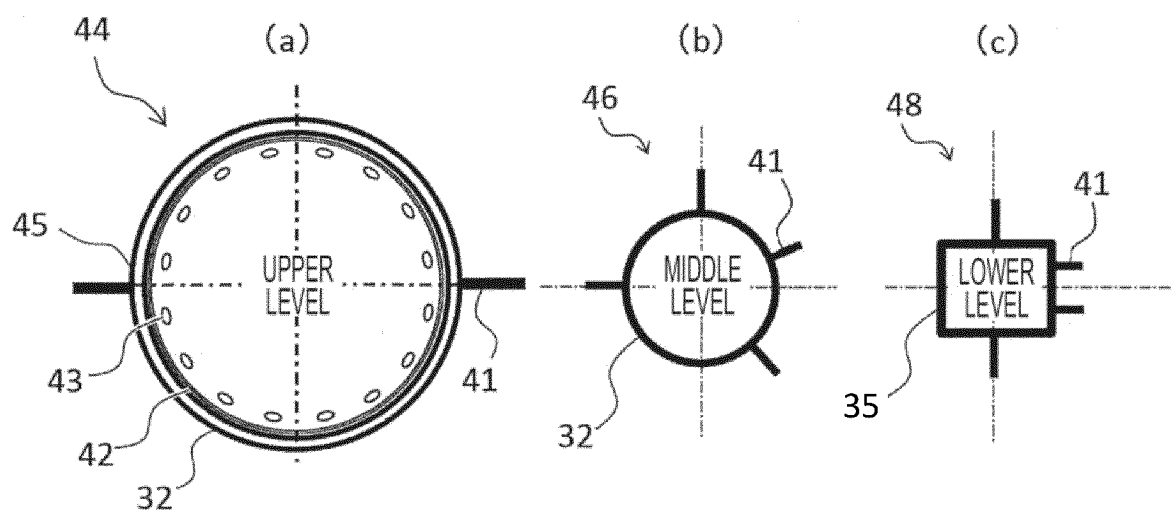


FIG. 3

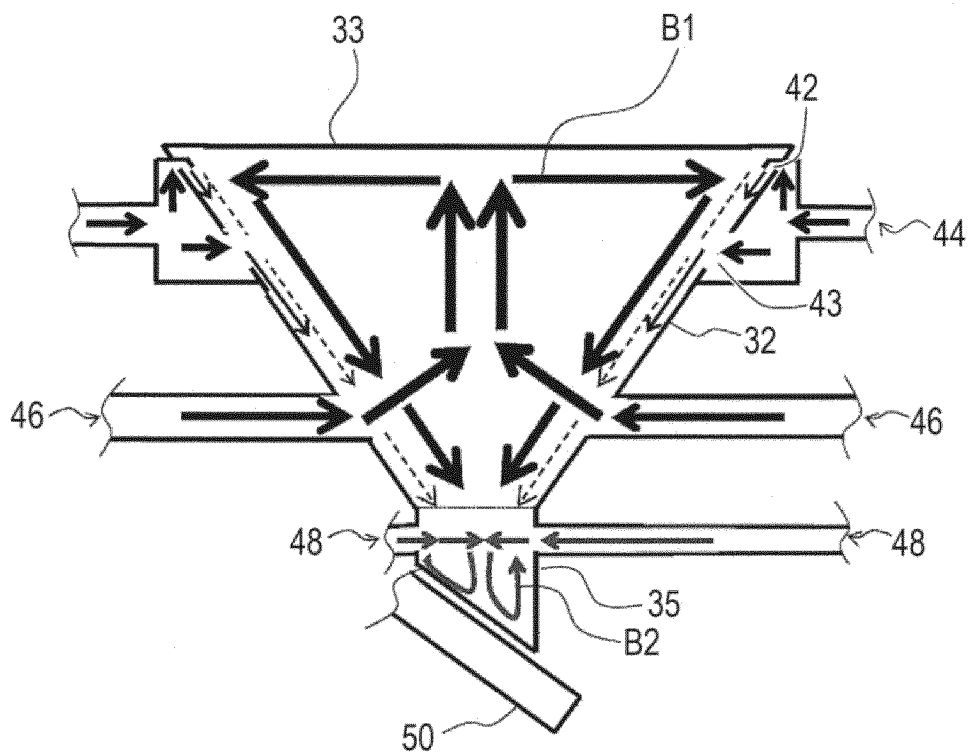


FIG. 4

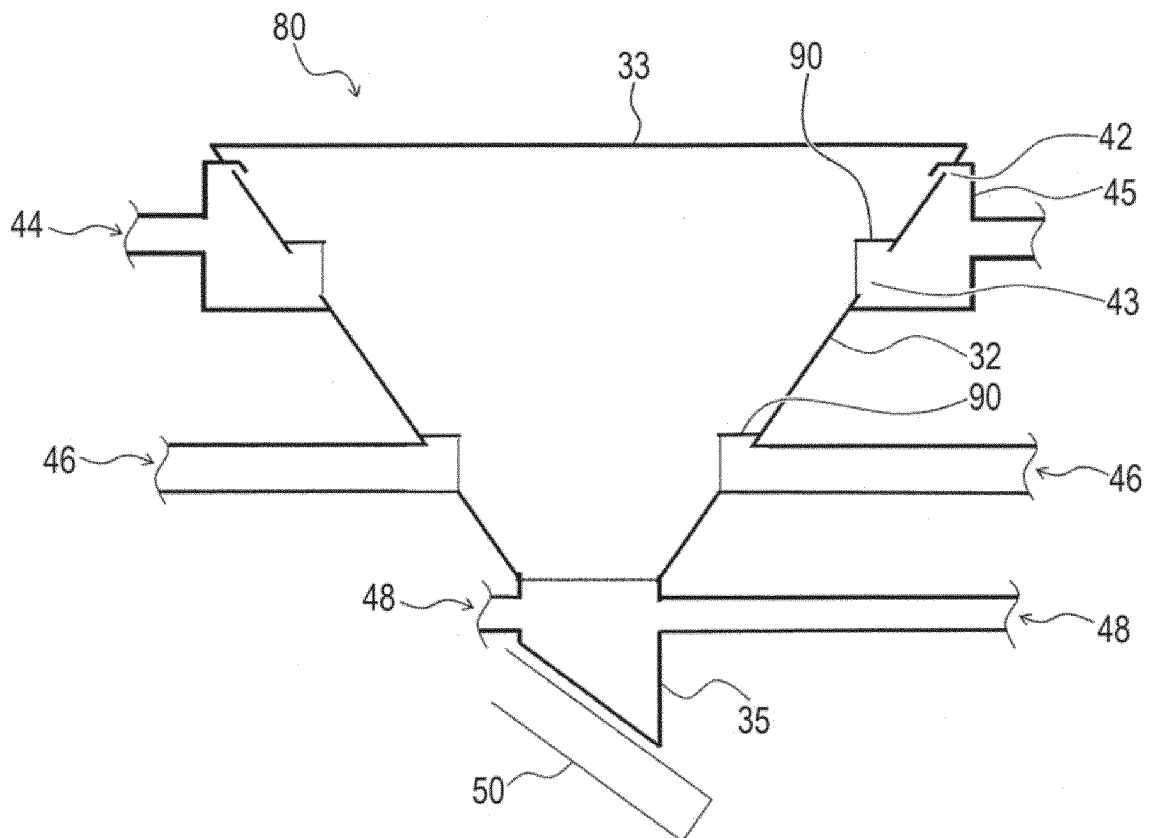


FIG. 5

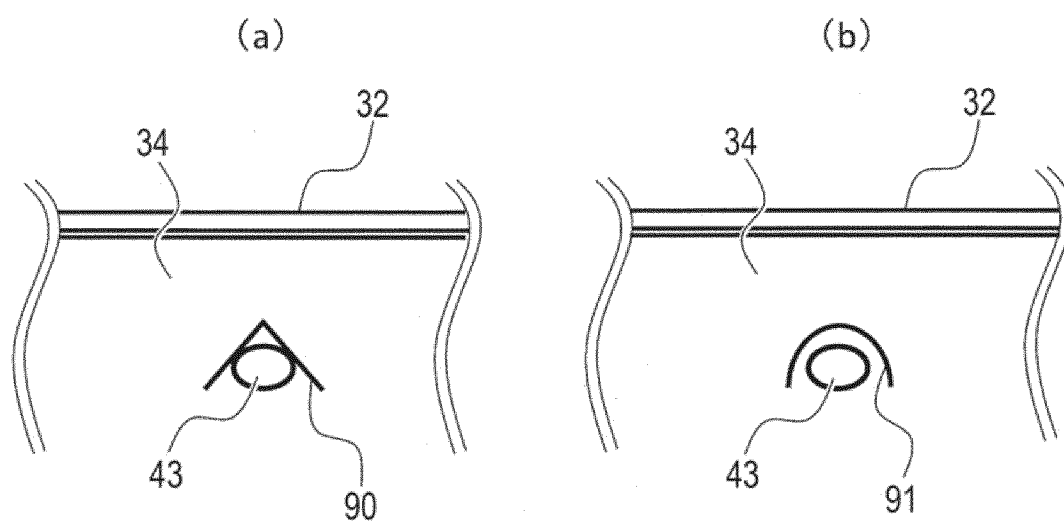


FIG. 6

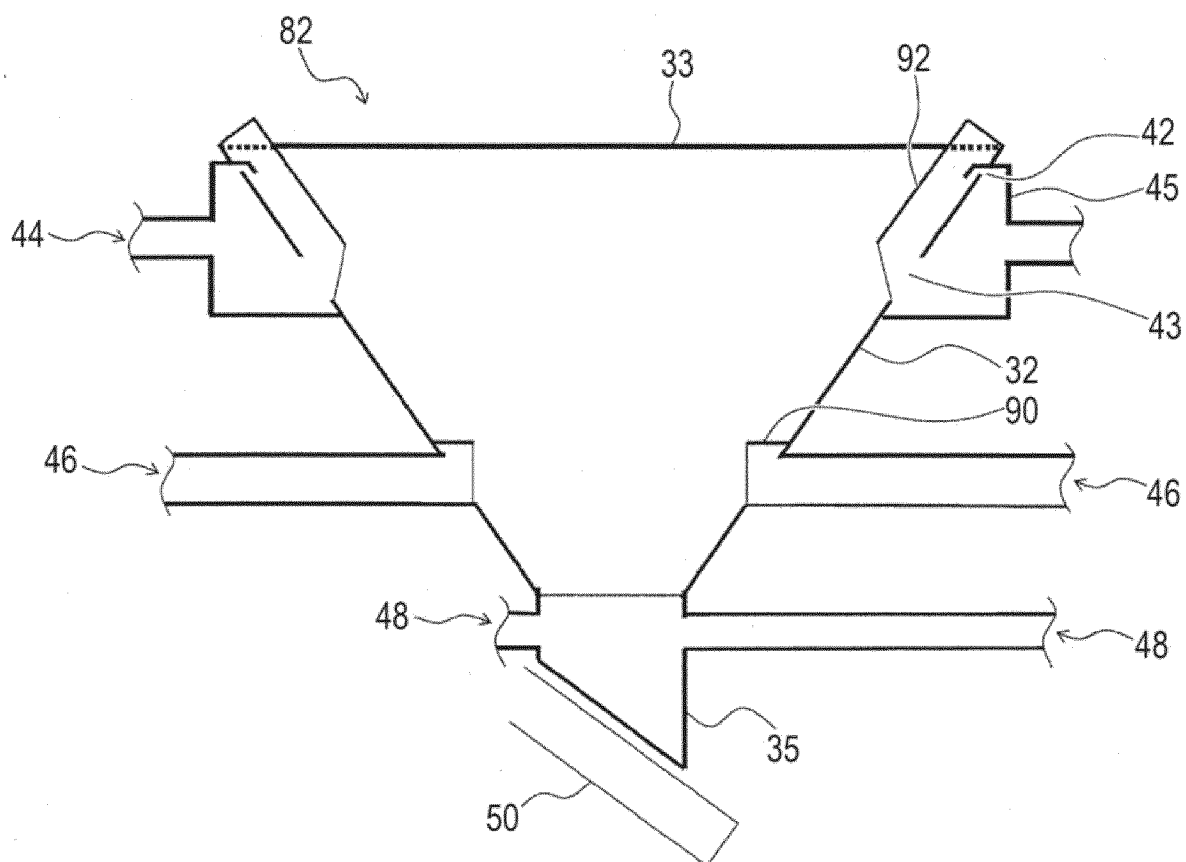


FIG. 7

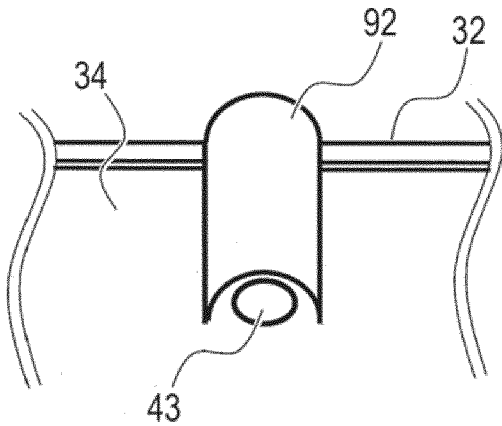


FIG. 8

|                                            | INVENTIVE EXAMPLE 1                                 | INVENTIVE EXAMPLE 2                                 |
|--------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|
| PIPE LAYOUT                                |                                                     |                                                     |
| PIPE COUNT [PIECE]                         | UPPER LEVEL/MIDDLE LEVEL/LOWER LEVEL=2/4/4          | UPPER LEVEL/MIDDLE LEVEL/LOWER LEVEL=1/4/3          |
| FLOW RATE DISTRIBUTION [m <sup>3</sup> /h] | UPPER LEVEL:MIDDLE LEVEL:LOWER LEVEL=1000:3500:500  | UPPER LEVEL:MIDDLE LEVEL:LOWER LEVEL=3000:1500:500  |
| PIPE DIAMETER [NOMINAL PIPE SIZE A]        | UPPER LEVEL/MIDDLE LEVEL/LOWER LEVEL=150A/400A/250A | UPPER LEVEL/MIDDLE LEVEL/LOWER LEVEL=150A/400A/250A |



FIG. 9

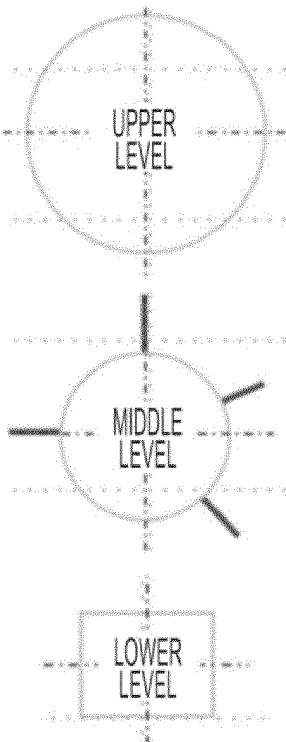
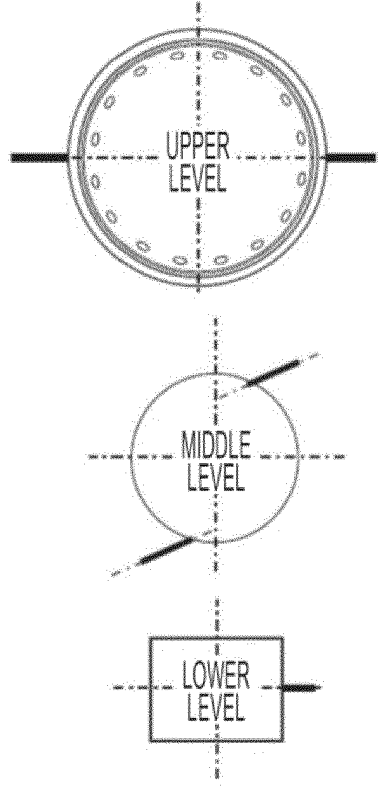
|                                            | COMPARATIVE EXAMPLE 1                                                              | COMPARATIVE EXAMPLE 2                                                               |
|--------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| PIPE LAYOUT                                |  |  |
| PIPE COUNT [PIECE]                         | UPPER LEVEL/MIDDLE LEVEL/LOWER LEVEL=0/4/0                                         | UPPER LEVEL/MIDDLE LEVEL/LOWER LEVEL=2/2/1                                          |
| FLOW RATE DISTRIBUTION [m <sup>3</sup> /h] | UPPER LEVEL:MIDDLE LEVEL:LOWER LEVEL=0:5000:0                                      | UPPER LEVEL:MIDDLE LEVEL:LOWER LEVEL=2000:2000:300                                  |
| PIPE DIAMETER [NOMINAL PIPE SIZE A]        | UPPER LEVEL/MIDDLE LEVEL/LOWER LEVEL = -/400A/-                                    | UPPER LEVEL/MIDDLE LEVEL/LOWER LEVEL = 150A/400A/250A                               |

FIG. 10

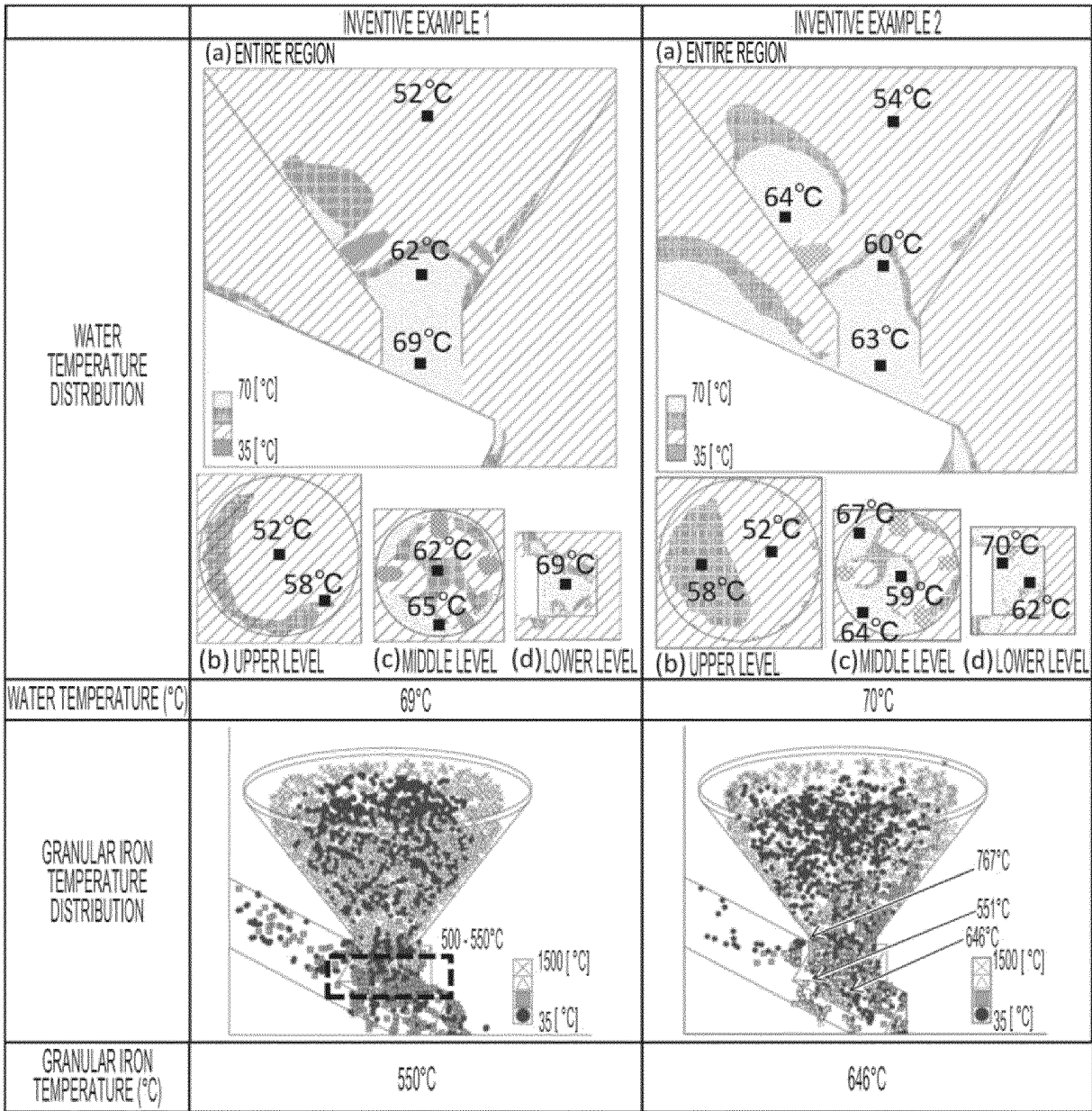


FIG. 11

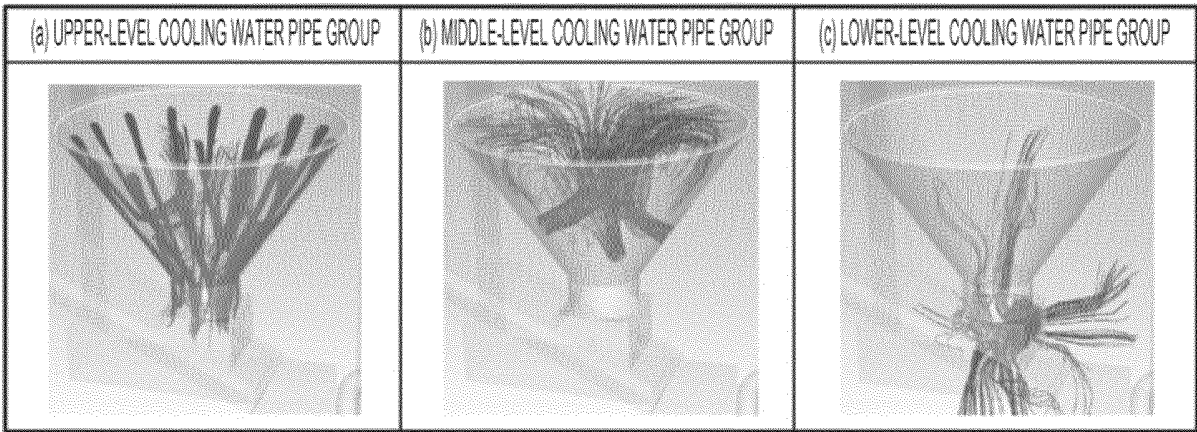


FIG. 12

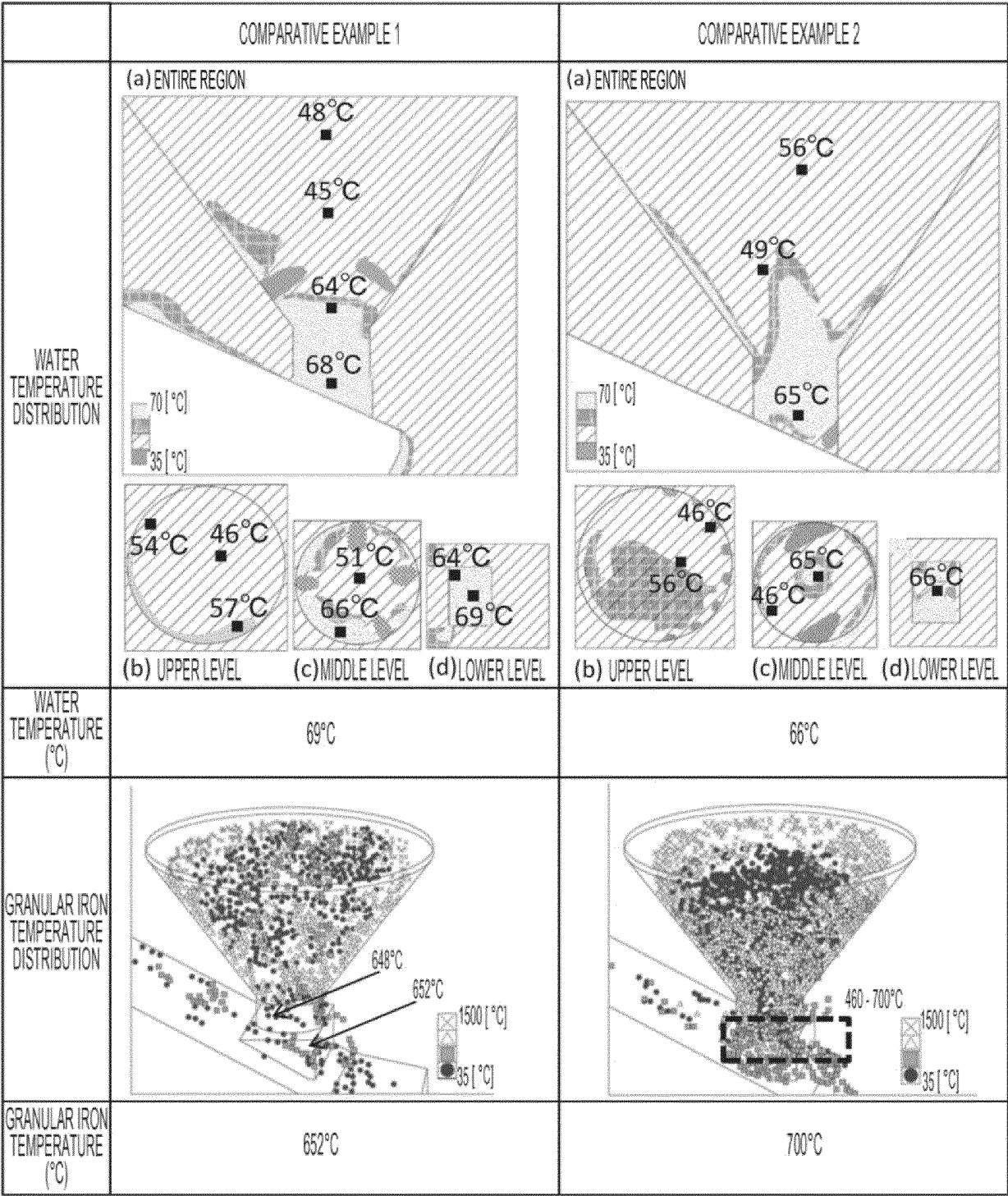
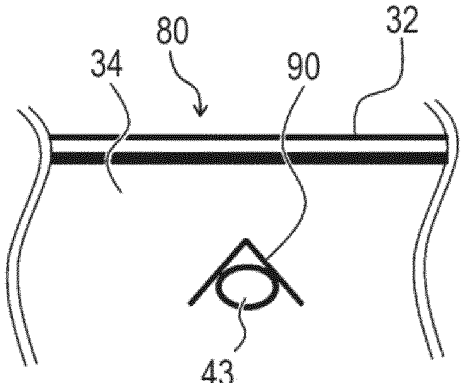
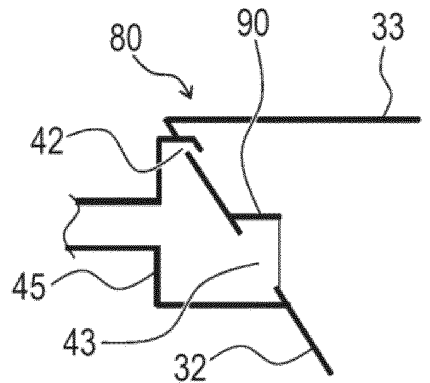
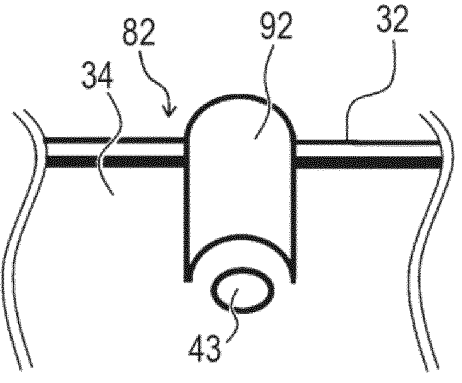
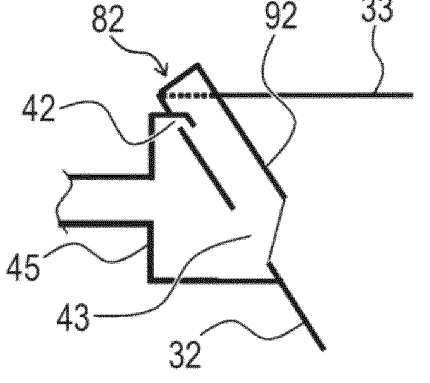


FIG. 13

|                        | ENTRY STATE OF GRANULAR IRON                                                        |                                                                                      |
|------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|                        | FRONT VIEW                                                                          | SECTIONAL VIEW                                                                       |
| INVENTIVE<br>EXAMPLE 3 |   |   |
| INVENTIVE<br>EXAMPLE 4 |  |  |

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/025176

| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br><b>B22F 9/08</b> (2006.01)i<br>FI: B22F9/08 C<br><br>According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                   | <b>B. FIELDS SEARCHED</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                    |                       |   |                                                                                             |     |   |                                                                                           |     |  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-----------------------|---|---------------------------------------------------------------------------------------------|-----|---|-------------------------------------------------------------------------------------------|-----|--|
| Minimum documentation searched (classification system followed by classification symbols)<br>B22F9/08                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br>Published examined utility model applications of Japan 1922-1996<br>Published unexamined utility model applications of Japan 1971-2023<br>Registered utility model specifications of Japan 1996-2023<br>Published registered utility model applications of Japan 1994-2023                                                                                                                                                                                                                                                                              |                                                                                    |                       |   |                                                                                             |     |   |                                                                                           |     |  |
| Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                    |                       |   |                                                                                             |     |   |                                                                                           |     |  |
| <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>JP 2021-127510 A (JFE STEEL CORP) 02 September 2021 (2021-09-02)<br/>all pages, all drawings</td> <td>1-8</td> </tr> <tr> <td>A</td> <td>JP 2021-161465 A (JFE STEEL CORP) 11 October 2021 (2021-10-11)<br/>all pages, all drawings</td> <td>1-8</td> </tr> </tbody> </table>                                                                                                                 | Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. | A | JP 2021-127510 A (JFE STEEL CORP) 02 September 2021 (2021-09-02)<br>all pages, all drawings | 1-8 | A | JP 2021-161465 A (JFE STEEL CORP) 11 October 2021 (2021-10-11)<br>all pages, all drawings | 1-8 |  |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Relevant to claim No.                                                              |                       |   |                                                                                             |     |   |                                                                                           |     |  |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | JP 2021-127510 A (JFE STEEL CORP) 02 September 2021 (2021-09-02)<br>all pages, all drawings                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1-8                                                                                |                       |   |                                                                                             |     |   |                                                                                           |     |  |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | JP 2021-161465 A (JFE STEEL CORP) 11 October 2021 (2021-10-11)<br>all pages, all drawings                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1-8                                                                                |                       |   |                                                                                             |     |   |                                                                                           |     |  |
| <input type="checkbox"/> Further documents are listed in the continuation of Box C.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                    |                       |   |                                                                                             |     |   |                                                                                           |     |  |
| * Special categories of cited documents:<br>“A” document defining the general state of the art which is not considered to be of particular relevance<br>“E” earlier application or patent but published on or after the international filing date<br>“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)<br>“O” document referring to an oral disclosure, use, exhibition or other means<br>“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<br>“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<br>“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<br>“&” document member of the same patent family |                                                                                    |                       |   |                                                                                             |     |   |                                                                                           |     |  |
| Date of the actual completion of the international search<br><b>04 August 2023</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Date of mailing of the international search report<br><b>15 August 2023</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                    |                       |   |                                                                                             |     |   |                                                                                           |     |  |
| Name and mailing address of the ISA/JP<br><b>Japan Patent Office (ISA/JP)</b><br><b>3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915</b><br><b>Japan</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Authorized officer<br><br><br>Telephone No.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                    |                       |   |                                                                                             |     |   |                                                                                           |     |  |

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INTERNATIONAL SEARCH REPORT  
Information on patent family members

International application No.  
**PCT/JP2023/025176**

| Patent document<br>cited in search report |             |   | Publication date<br>(day/month/year) | Patent family member(s) | Publication date<br>(day/month/year) |
|-------------------------------------------|-------------|---|--------------------------------------|-------------------------|--------------------------------------|
| JP                                        | 2021-127510 | A | 02 September 2021                    | (Family: none)          |                                      |
| JP                                        | 2021-161465 | A | 11 October 2021                      | (Family: none)          |                                      |

**REFERENCES CITED IN THE DESCRIPTION**

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