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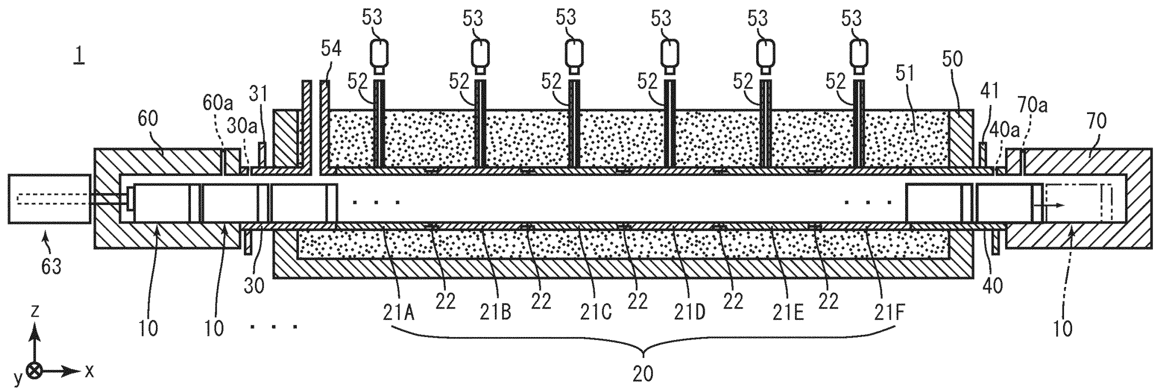
# (54) HEAT TREATMENT APPARATUS

(57) A heat treatment apparatus is provided that can control temperature distribution with good reproducibility. A heat treatment apparatus (1) includes: a tubular heater (20); a pair of troughs (30), (40) each constituted by a graphite pipe and connected to the corresponding end of the heater (20); and a pair of electrodes (31), (41) each provided on the corresponding trough (30), (40). The heater (20) includes: a first graphite pipe (21B); a second graphite pipe (21C) having one end side in contact with one end side of the first graphite pipe (21B) and having an electrical resistance higher than that of the first graphite pipe (21B); and a third graphite pipe (21D) having one end side in contact with the other end side of the second graphite pipe (21C) and having an electrical resistance lower than that of the second graphite pipe (21C).

*Fig.2*

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## Description

### TECHNICAL FIELD

**[0001]** The present invention relates to a heat treatment apparatus.

### BACKGROUND ART

**[0002]** Carbon materials, particularly graphite, have special properties such as high electrical conductivity, high thermal conductivity, chemical resistance and self-lubricity, and are thus widely used in various applications as material for metallurgy and for electrical and electronic products and machines. Recently, the trend has been to develop a graphite crystal through high-temperature heat treatment to improve thermal conductivity, where the resulting graphite is used as a heat sink or heat-dissipating board or as a negative-electrode material for a lithium-ion secondary battery, for example.

**[0003]** Graphite may be obtained through heat treatment of a graphite material such as a resin, such as phenol or furan, or coke or meso-carbon at temperatures of 2000 to 3200 °C, for example.

**[0004]** JP 2002-69757 A discloses a carbon fiber and a method and apparatus for manufacturing it. Japanese Patent No. 2744617 discloses a method and apparatus for successively graphitizing a vapor-phase-growth carbon fiber.

**[0005]** Japanese Patent No. 3787241 discloses an apparatus for manufacturing graphite in which a plurality of cylindrical graphite pipes are connected to form a heating tube and an inlet unit for raw material for graphite is attached to one end of the heating tube and an outlet unit for the resulting graphite product is attached to the other end of the heating tube. In this apparatus for manufacturing graphite, ones of the graphite pipes forming the heating tube that have larger resistances are located toward the inlet unit. This patent states that, as graphite pipes with larger resistances are provided in regions adjacent to the inlet unit, in which the temperature tends to be low, the temperature distribution in the heating tube can be uniform.

### DISCLOSURE OF THE INVENTION

**[0006]** In the arrangements of the above-discussed apparatus for manufacturing graphite, it may be difficult to control temperature distribution with good reproducibility.

**[0007]** An object of the present invention is to provide a heat treatment apparatus that can control temperature distribution with good reproducibility.

**[0008]** The heat treatment apparatus disclosed herein includes: a tubular heater; a pair of troughs each constituted by a graphite pipe and connected to a corresponding end of the heater; and a pair of electrodes each provided on the corresponding trough. The heater includes: a first graphite pipe; a second graphite pipe having one end side in contact with one end side of the first graphite pipe and having an electrical resistance higher than that of the first graphite pipe; and a third graphite pipe having one end side in contact with another end side of the second graphite pipe and having an electrical resistance lower than that of the second graphite pipe.

**[0009]** In the above-disclosed arrangement, the heater includes three graphite pipes connected in series (i.e. first to third graphite pipes), where the middle graphite pipe (i.e. second graphite pipe) has the highest electrical resistance. The heater is supplied with electric power via the electrodes electrically connected to the ends of the heater. Since the first to third graphite pipes are connected in series, the same amount of current flows through the first to third graphite pipes. As such, the second graphite pipe, which has the highest electrical resistance, generates the greatest amount of heat. Thus, the heat treatment apparatus forms a temperature distribution that is upward-convex.

**[0010]** The temperature distribution in the heat treatment apparatus varies depending on set temperature, the wear of components, the heat capacity of material being treated, and other factors. In the above arrangement, intentionally providing a convex temperature distribution ensures that the point of highest temperature is at the same position for each run. This will make it easier to control temperature and provide a temperature distribution with high reproducibility.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0011]**

[FIG. 1] FIG. 1 is a schematic plan view of a heat treatment apparatus.
[FIG. 2] FIG. 2 is a cross-sectional view of the apparatus taken along line II-II in FIG. 1.
[FIG. 3] FIG. 3 is a schematic exploded perspective view of the heater.
[FIG. 4] FIG. 4 is a cross-sectional view of the heater taken along line IV-IV of FIG. 3.
[FIG. 5] FIG. 5 is a functional block diagram of the heat treatment apparatus.
[FIG. 6] FIG. 6 shows an example of temperature distribution within the heat treatment apparatus.
[FIG. 7] FIG. 7 shows an example of temperature distribution in the heat treatment apparatus according to an imaginary comparative example.
[FIG. 8] FIG. 8 shows how inert gas flows within the heat treatment apparatus.

### EMBODIMENTS FOR CARRYING OUT THE INVENTION

[Embodiments]

**[0012]** An embodiment of the present invention will now be described in detail with reference to the drawings.

In the drawings, the same or corresponding elements are labeled with the same reference characters and their description will not be repeated. For ease of explanation, the drawings to which reference will be made below show the components in a simplified or schematic manner, or do not show some of the components. The size ratios between the components shown in the drawings do not necessarily represent their actual size ratios.

[Overall Construction]

**[0013]** FIG. 1 is a schematic plan view of a heat treatment apparatus 1 according to one embodiment of the present invention. FIG. 2 is a cross-sectional view of the apparatus taken along line II-II in FIG. 1. The heat treatment apparatus 1 includes a heater 20, troughs 30 and 40, a furnace wall 50, and chambers 60 and 70.

**[0014]** The heat treatment apparatus 1 moves crucibles 10 through the interior of the cylindrical heater 20 along its axial direction to successively perform heat treatment. The heater 20 also serves as the furnace core tube of the heat treatment apparatus 1.

**[0015]** Each crucible 10 includes a tubular container 11 with a bottom, and a lid 12 closing the opening of the container 11. The crucible 10 contains material to be treated, which is to be subjected to heat treatment. The material to be treated may be, for example, powder of a resin such as phenol or furan, or coke or meso-carbon

**[0016]** The heater 20 is composed of six graphite pipes 21A, 21B, ..., and 21F. The graphite pipes 21A, 21B, ..., 21F are arranged to share the same axis, where an end side of a pipe is coupled with an end side of another pipe. A connection ring 22 made of graphite is fitted to the connection portion of adjacent ones of the graphite pipes 21A, 21B, ..., 21F to fix their radial position.

**[0017]** The ends of the heater 20 are connected to the troughs 30 and 40. Similar to the heater 20, the troughs 30 and 40 are made of an electrically conductive heat-resistant material, such as graphite. The troughs 30 and 40 are cylindrical in shape and have the same inner diameter as the heater 20.

**[0018]** The entire heater 20 and parts of the troughs 30 and 40 are surrounded by the furnace wall 50, which is made of fireproof blocks or the like. The space defined by the furnace wall 50 is filled with an insulating material 51. The insulating material 51 may be graphite powder, for example.

**[0019]** Electrodes 31 and 41 are provided on portions of the troughs 30 and 40, respectively, that are not covered with the furnace wall 50. The electrodes 31 and 41 are supplied with electric power by a power source 85 (FIG. 5), discussed below. The electrodes 31 and 41 are electrically connected to the heater 20 via the troughs 30 and 40. In the heat treatment apparatus 1, the heater 20 is heated by causing electric current to flow through the heater 20.

**[0020]** A plurality of temperature measurement tubes 52 are provided inside the furnace wall 50 to be in contact with the periphery of the heater 20. The temperature of the heater 20 is measured by a plurality of radiation thermometer 53 (FIG. 2).

**[0021]** Gas inlets 30a and 40a are formed in the troughs 30 and 40, respectively. A gas discharge tube 54 is provided inside the furnace wall 50 to communicate with the interior of the trough 30. An inert gas such as nitrogen or argon is introduced into the interior of the heater 20 through the gas inlets 30a and 40a. Inert gas that has been introduced is discharged through the gas discharge tube 54 together with impurities that have been volatilized by heat treatment.

**[0022]** The troughs 30 and 40 are connected to the chambers 60 and 70, respectively. As shown in FIG. 1, the chamber 60 includes a shutter 61. The chamber 70 includes a shutter 71. The heat treatment apparatus 1 further includes conveyors 62 and 72, a push-in device 63, and a direction-reversing device 64. Further, gas inlets 60a and 70a are formed in the chambers 60 and 70, respectively. Inert gas is also introduced through the gas inlets 60a and 70a.

**[0023]** A plurality of crucibles 10 are loaded into the interior of the heater 20, where the crucibles are in contact with each other. In the heat treatment apparatus 1, a crucible 10 at the chamber 60 is pushed in by the push-in device 63. Thus, the crucibles 10 in the heater 20 move toward the chamber 70.

**[0024]** In the heat treatment apparatus 1, the shutter 61 and conveyor 62 are driven to transport a crucible 10 before heat treatment into the chamber 60. In the heat treatment apparatus 1, the shutter 71 and conveyor 72 are driven to transport a crucible 10 after heat treatment out of the chamber 70. The heat treatment apparatus 1 repeats these steps to successively perform heat treatment on the crucibles 10.

**[0025]** The direction-reversing device 64 is located on the path of transport by the conveyor 62. The direction-reversing device 64 may be a mechanical arm, for example, for grasping a crucible 10 from above the conveyor 62 and rotating it. The direction-reversing device 64 rotates the crucible 10 such that the lid 12 faces toward the chamber 70. As the lid 12 faces toward the chamber 70, the lid 12 is prevented from being broken by a pressing force by the push-in device 63.

[Construction of Heater 20]

**[0026]** FIG. 3 is a schematic exploded perspective view of the heater 20. FIG. 4 is a cross-sectional view of the heater along line IV-IV in FIG. 3. In FIGS. 3 and 4, each of the graphite pipes 21A, 21B, ..., 21F is not distinguished and is simply referred to as graphite pipe 21.

**[0027]** As discussed above, the graphite pipes 21A, 21B, ..., 21F are arranged to share the same axis such that their end sides are in contact with each other. More specifically, the graphite pipe 21A is positioned such that one end side is in contact with one end side of the graphite pipe 21B, the graphite pipe 21B is positioned such that the other end side is in contact with one end side of the graphite pipe 21C, ..., and the graphite pipe 21E is positioned such that the other end side is in contact with one end side of the graphite pipe 21F.

**[0028]** That is, the graphite pipes 21A and 21B, the graphite pipes 21B and 21C, ..., and the graphite pipes 21E and 21F are in contact with each other at their end sides. Thus, the graphite pipes 21A, 21B, ..., 21F are electrically connected in series.

**[0029]** According to the present embodiment, the following relationships are satisfied:

$\rho_C>\rho_B>\rho_A$; and
$\rho_C>\rho_D>\rho_E>\rho_F$,

where $\rho_A$, $\rho_B$, ..., $\rho_F$ are the electrical resistances of the graphite pipes 21A, 21B, ..., 21F, respectively.

**[0030]** That is, according to the present embodiment, the closer a graphite pipe to the center of the heater 20 as determined along the axial direction, the higher the electrical resistance. In other words, the more distant a graphite pipe from the electrodes 31 and 32, the higher the electrical resistance. According to the present embodiment, the graphite pipe 21C has the highest electrical resistance.

**[0031]** According to the present embodiment, $\rho_A$, $\rho_B$, ..., $\rho_F$ further satisfy the following relationship:

$\rho_C>\rho_D>\rho_B>\rho_E>\rho_F>\rho_A$.

**[0032]** As discussed above, the connection rings 22 are fitted to the connection portions of the graphite pipes 21A, 21B, ..., 21F. This prevents the graphite pipes 21A, 21B, ..., 21F from being displaced in a radial direction (i.e. direction perpendicular to the x-direction).

**[0033]** Each end of each of the graphite pipes 21A, 21B, ..., 21F has a groove 21a formed therein that has a smaller outer diameter R2 than the outer diameter R1 of the heater 20. As shown in FIG. 4, each connection ring 22 is fitted to the recess formed by the grooves 21a of two graphite pipes. This restricts the movement of the connection ring 22 in the axial direction of the heater 20 (x-direction). This prevents the connection ring 22 from being displaced in the axial direction, thereby ultimately preventing the central axes of the two graphite pipes from being displaced from each other.

**[0034]** The graphite pipes 21A, 21B, ..., 21F and connection rings 22 are preferably made of the same material, because this will make the coefficient of thermal expansion of the graphite pipes 21A, 21B, ..., 21F equal to the coefficient of thermal expansion of the connection rings 22, thereby preventing a stress from being produced at a connection portion.

**[0035]** According to the present embodiment, the outer diameter R1 of the heater 20 is equal to the outer diameter of the connection rings 22. In other words, the depth of the grooves 21a is equal to the wall thickness of the connection rings 22. If the connection rings 22 protruded from the heater 20, this would increase the surface area, increasing the amount of heat dissipation. As the connection rings 22 do not protrude from the heater 20, heat dissipation can be minimized. It should be noted that the outer diameter R1 of the heater 20 and the outer diameter of the connection rings 22 need not be exactly equal, but are only required to be substantially equal.

[Method of Controlling Temperature of Heat Treatment Apparatus 1]

**[0036]** An example of a method of controlling the temperature of the heat treatment apparatus 1 will be described. However, the method of controlling the temperature of the heat treatment apparatus 1 is not limited to this example.

**[0037]** FIG. 5 is a functional block diagram of the heat treatment apparatus 1. The heat treatment apparatus 1 further includes a temperature controller 80 and a power source 85.

**[0038]** The temperature controller 80 includes a plurality of analog/digital converters (ADCs) 81, a calculation device 82, a storage 83, and a digital/analog converter (DAC) 84.

**[0039]** The calculation device 82 includes a comparator 821 for selecting the maximum value from a plurality of values that have been supplied, and an output determiner 822 for deciding the output of the power source 85. The comparator 821 and output determiner 822 may be hardware, such as dedicated circuitry, or software implemented by executing a program based on information stored in the storage 83.

**[0040]** The temperature controller 80 is supplied with temperature measurements from the radiation thermometers 53 via the ADCs 81. The comparator 821 selects, from the temperature measurements obtained by the radiation thermometers 53, the maximum value which will be referred to as measured temperature, and supplies it to the output determiner 822.

**[0041]** The storage 83 stores a set temperature provided via an input device, not shown. At regular intervals, the output determiner 822 calculates the deviation between the set temperature stored in the storage 83 and the measured temperature supplied by the comparator 821, and stores it in the storage 83. The output determiner 822 decides the output of the power supply 85 based on the deviation, the time integration of the deviation and the time derivative of the deviation.

**[0042]** The set temperature for heat treatment of the material to be treated may be, for example, 2000 to 3200 °C, and preferably 2200 to 3000 °C.

**[0043]** The power source 85 is informed of the output decided by the output determiner 822 via the DAC 84. The power source 85 supplies the amount of electric power proportional to the output to the heater 20.

**[0044]** Thus, according to the present embodiment, the highest temperature of the heater 20 is treated as the measured temperature, and the output of the power source 85 is adjusted such that the measured temperature is equal to the set temperature.

[Effects of Heat Treatment Apparatus 1]

**[0045]** FIG. 6 shows an example of temperature distribution within the heat treatment apparatus 1. The horizontal axis of FIG. 6 represents the position determined along the axial direction of the heater 20, and A, B, ..., F represent the positions at which the graphite pipes 21A, 21B, ..., 21F, respectively, are located.

**[0046]** The heater 20 is supplied with electric power through both ends via the electrodes 31 and 41. The graphite pipes 21A, 21B, ..., 21F are electrically connected in series such that the same amount of current flows through all of the graphite pipes 21A, 21B, ..., 21F. Thus, the larger the electrical resistance of a graphite pipe, the larger the amount of heat generated.

**[0047]** According to the present embodiment, the closer a graphite pipe to the center of the heater as determined along its axial direction, the larger the electrical resistance. Thus, the closer to the center of the heater 20 as determined along its axial direction, the larger the amount of heat generated. Thus, as shown in FIG. 6, the temperature distribution in the heat treatment apparatus 1 is upward-convex in shape, with its peak located in the vicinity of the center of the heater 20.

**[0048]** According to the present embodiment, the temperature of the heat treatment apparatus 1 can be easily controlled. The effects of this arrangement will be described in comparison with an imaginary comparative example. FIG. 7 is an example of temperature distribution in the heat treatment apparatus according to an imaginary comparative example. This heat treatment apparatus is designed to produce a flat temperature distribution within the apparatus.

**[0049]** During real heat treatment, the shape of the temperature distribution within the apparatus changes for each run of heat treatment due to set temperature, the heat capacity of the material being treated, the wear of the heater 20 or insulating material 51 and other factors. Thus, if the temperature distribution is as shown in FIG. 7, the point of highest temperature may vary in position for each run of heat treatment.

**[0050]** In this situation, if the temperature at one point in the heater 20 is measured and the output of the power source 85 is controlled accordingly, the highest temperature in the apparatus may become higher than the set temperature. It is thought that the properties of the material under heat treatment are affected by the highest temperature during treatment more strongly than the average temperature. Thus, it is undesirable that the highest temperature in the apparatus may become higher than the set temperature.

**[0051]** Further, if the temperature distribution is as in FIG. 7, the point of highest temperature may change in position, e.g., the point of highest temperature during one run of heat treatment may be located at the graphite pipe 21B and the point of highest temperature during another run of heat treatment may be located at the graphite pipe 21E, such that the temperature of a crucible 10 may be raised at a different rate for each run of heat treatment.

**[0052]** According to the present embodiment, the temperature distribution is intentionally made convex such that the point of highest temperature generally stays at the same position for each run. Accordingly, only the temperature of that area must be controlled, which means that the temperature can be controlled relatively easily. Further, as the point of highest temperature generally stays at the same position, the history of heat applied to material being treated is constant. This will achieve heat treatment with high reproducibility.

**[0053]** Further, according to the present embodiment, heat dissipation from the ends of the heater 20 can be minimized. This will enable more efficient heating than with the temperature distribution as in FIG. 7.

**[0054]** Of the graphite pipes forming the heater 20 of the present embodiment, the graphite pipe 21C has the largest electrical resistance; on the other hand, in the example of FIG. 6, the point of highest temperature is located at the graphite pipe 21D. This is because crucibles 10 having low temperatures are transported from the chamber 60, causing the temperature of areas near the chamber 60 to decrease. As can be understood from this, the position at which the graphite pipe with the largest electrical resistance is located need not coincide with the position of the point of highest temperature.

**[0055]** According to the present embodiment, $\rho_A$, $\rho_B$, ..., $\rho_F$ satisfies the relationship $\rho_C>\rho_D>\rho_B>\rho_E>\rho_F>\rho_A$. That is, the electrical resistances of the graphite pipes (21B and 21C) that are located closer to the chamber 60 than the center of the heater 20 determined along its axial direction is are higher than those of the pipes closer to the chamber 70 (21D and 21E). As discussed above, temperature is low in areas of the heater 20 near the chamber 60 since crucibles 10 with low temperature are transported from the chamber 60. The amount of heat generated by graphite pipes closer to the chamber 60 is increased by making the electrical resistances of graphite pipes closer to the chamber 60 relatively high. This provides a temperature distribution that is more symmetrical with respect to the center of the heater 20. However, the electrical resistance $\rho_A$ of the graphite pipe 21A is lower than the electrical resistance $\rho_F$ of the graphite pipe 21F. This provides a relatively small amount of heat generated at the graphite pipe 21A to provide a gentle change in temperature at the beginning of heating of material being treated.

**[0056]** The heat treatment apparatus 1 includes a plurality of radiation thermometers 53. Further, the temperature controller 80 (FIG. 5) includes a comparator 821 for selecting the maximum value from a plurality of temperature measurements. This arrangement will prevent the highest temperature in the apparatus from becoming higher than the set temperature even when the point of the highest temperature changes in position.

**[0057]** Further, the arrangement of the present embodiment facilitates purification of material being treated, as will be discussed below.

**[0058]** Impurities having melting points lower than the material being treated are volatilized by heat treatment and removed from the material. At this time, the higher the temperature, the higher the equilibrium vapor pressure of the impurities and the larger the amount of impurities volatilized. However, when the partial pressure of the impurities reaches the equilibrium vapor pressure, no impurities volatilize.

**[0059]** According to the present embodiment, the temperature distribution in the heat treatment apparatus 1 is upward-convex in shape, with its peak located in the vicinity of the center of the heater 20. Similarly, the distribution of concentration of volatilized impurities is also upward-convex in shape. Volatilized impurities diffuse from positions with high concentration to positions with low concentration. This decreases the concentration of impurities at the peak. The partial pressure of impurities at the peak becomes lower than the equilibrium vapor pressure, causing more impurities to volatilize. This process is repeated such that impurities are successively removed from material being treated.

**[0060]** When the temperature distribution is flat as shown in FIG. 7, the distribution of concentration of volatilized impurities is flat such that no diffusion occurs. As such, when the partial pressure of impurities reaches the equilibrium vapor pressure, impurities do not volatilize anymore. In contrast, according to the present embodiment, the temperature distribution in the apparatus forms a concentration gradient of impurities, thereby facilitating purification of material being treated, using diffusion.

**[0061]** FIG. 8 shows how inert gas flows within the heat treatment apparatus 1. In FIG. 8, hollow arrows schematically indicate the flow of inert gas. According to the present embodiment, a gas inlet 40a is provided on the trough 40 located closer to the chamber 70 than the heater 20 is. Further, a gas discharge tube 54 is provided that communicates with the trough 30 located closer to the chamber 60 than the heater 20 is. In this arrangement, inert gas in the heater 20 flows from the chamber 70 toward the chamber 60.

**[0062]** On the other hand, crucibles 10 are moved by the push-in device 63 from the chamber 60 toward the chamber 70. That is, according to the present embodiment, inert gas flows in the direction opposite to the direction in which crucibles 10 move.

**[0063]** In this arrangement, impurities removed from the material being treated placed in a crucible 10 are moved by the inert gas in the direction opposite to the direction in which the crucible 10 is moving. As such, impurities do not adhere back to this particular crucible 10. It is possible that impurities may adhere to a crucible 10 located downstream of that particular crucible 10 as determined along the direction in which the gas flows; however, it is expected that, when the crucible 10 located downstream moves past the point of highest temperature, impurities that have adhered will volatilize again and be removed. This will improve the purity of the material under heat treatment.

**[0064]** According to the present embodiment, the gas discharge tube 54 is located in an area covered with the insulating material 51. That is, the gas discharge tube 54 is located in a high-temperature area. In this arrangement, volatilized impurities are discharged through the gas discharge tube 54 before solidifying again. This will prevent impurities from being deposited within the apparatus, thereby improving the purity of the material under heat treatment.

**[0065]** According to the present embodiment, the gas inlet 40a is provided on the trough 40 and the gas discharge tube 54 is provided to communicate with the trough 30. However, the gas inlet and gas discharge tube are not limited to these positions. The gas inlet and gas discharge tube are only required to be positioned such that inert gas in the heater 20 flows in the direction opposite to the direction in which crucibles 10 move. For example, the gas inlet 40a may be replaced by a gas inlet tube that communicates with the heater portion 21F. Or, the gas discharge tube 54 may be replaced by a gas discharge tube that communicates with the heater portion 21A.

**[0066]** The gas inlet is preferably located downstream of the point of highest temperature in the heater 20 as determined along the direction in which crucibles 10 move, i.e. located closer to the chamber 70 than the point of highest temperature is. The gas discharge tube is preferably located upstream of the point of highest temperature in the heater 20 as determined along the direction in which crucibles 10 move, i.e. located closer to the chamber 60 than the point of highest temperature. Further, the gas discharge tube is preferably located at a position at which the temperature in the heater 20 is higher than the melting points of impurities in material being treated.

[Other Embodiments]

**[0067]** Although an embodiment of the present invention has be described, the present invention is not limited to the above-described embodiment, and various modifications are possible within the scope of the invention.

**[0068]** The above-described embodiment describes an implementation where the heater 20 is cylindrical in shape. However, the heater 20 is only required to be tubular in shape, and the heater 20 and graphite pipes 21A, 21B, ..., 21F may have any cross-sectional shape.

**[0069]** The above-described embodiment shows a plurality of graphite pipes with the same length; however, the graphite pipes may have different lengths.

**[0070]** The above-described embodiment describes an implementation where $\rho_A$, $\rho_B$, ..., $\rho_F$ satisfy the following relationships:

$\rho_C > \rho_B > \rho_A$, and

$\rho_C > \rho_D > \rho_E > \rho_F$.

**[0071]** However, $\rho_A$, $\rho_B$, ..., $\rho_F$ may have the following relationships:

$\rho_C = \rho_D$,
$\rho_C > \rho_B > \rho_A$, and
$\rho_D > \rho_E > \rho_F$.

**[0072]** These relationships also provide a temperature distribution that is upward-convex. In this implementation, the graphite pipes 21C and 21D may be substantially treated as one graphite pipe.

**[0073]** The above-described embodiment describes an implementation where the heater 20 is composed of six graphite pipes. However, the number of graphite pipes forming the heater is any number greater than two (2).

**[0074]** That is, the heater may include three graphite pipes connected in series where the middle graphite pipe has the highest electrical resistance. In other words, the heater may include a first graphite pipe, a second graphite pipe having one end side in contact with one end side of the first graphite pipe and having an electrical resistance higher than that of the first graphite pipe, and a third graphite pipe having one end side in contact with the other end side of the second graphite pipe and having an electrical resistance lower than that of the second graphite pipe.

**[0075]** The above-described embodiment describes an implementation where the heater 20 also serves as the furnace core tube. Alternatively, the heat treatment apparatus 1 may include a furnace core tube separate from the heater 20.

**[0076]** The above-described embodiment describes an implementation where the heat treatment apparatus 1 includes chambers 60 and 70. Alternatively, the heat treatment apparatus 1 may include only one or none of the chambers 60 and 70 and a shutter may be provided on the entrance of the trough 30 or the exit of the trough 40. Further, the conveyors 62 and 72 may be absent. Or, the conveyors 62 and 72 may be replaced by slopes or the likes.

## Claims

**1.** A heat treatment apparatus comprising:

a tubular heater;
a pair of troughs each constituted by a graphite pipe and connected to a corresponding end of the heater; and
a pair of electrodes each provided on the corresponding trough,
wherein the heater includes:

a first graphite pipe;
a second graphite pipe having one end side in contact with one end side of the first graphite pipe and having an electrical resistance higher than that of the first graphite pipe; and
a third graphite pipe having one end side in contact with another end side of the second graphite pipe and having an electrical resistance lower than that of the second graphite pipe.

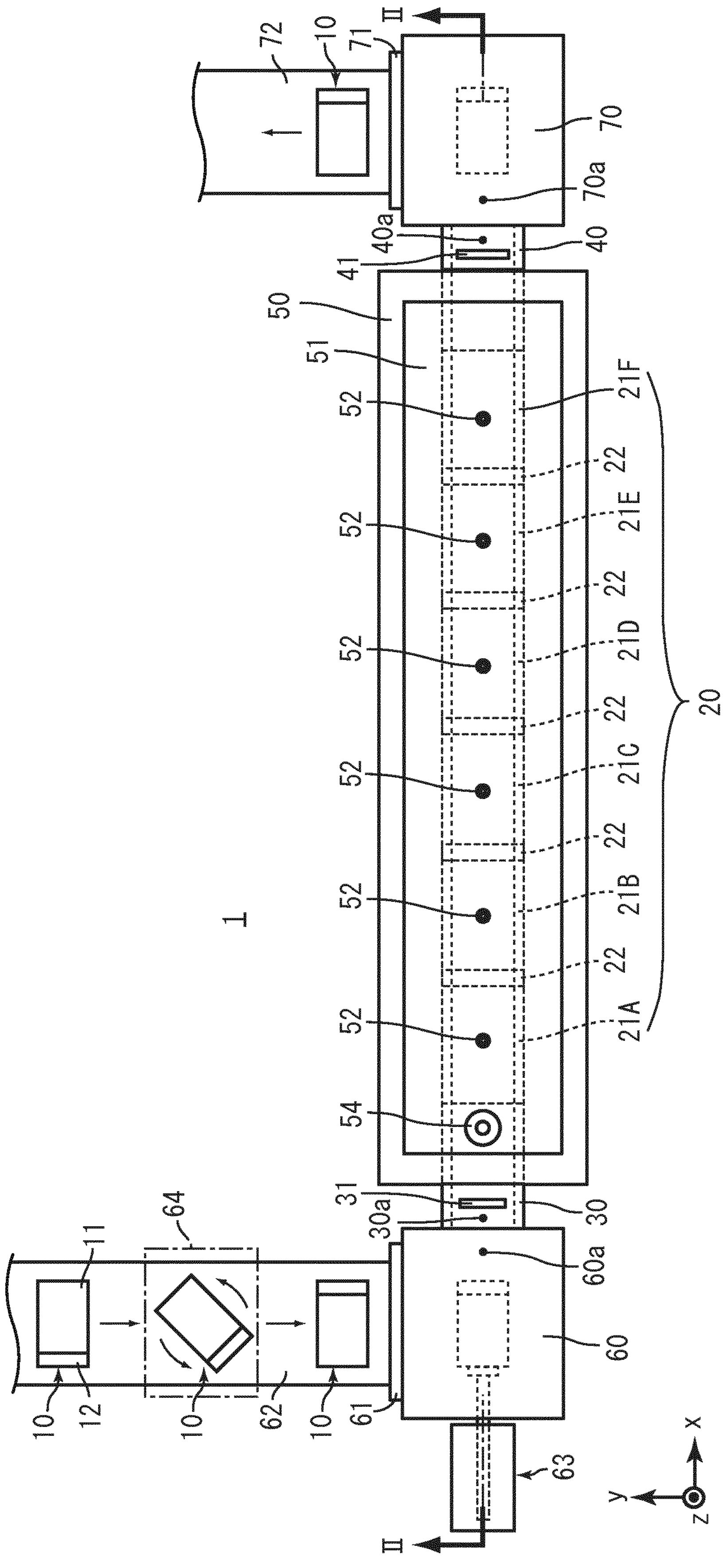
**2.** The heat treatment apparatus according to claim 1, further comprising:

a push-in device located adjacent to one opening of the heater for pushing material to be treated toward another opening of the heater;
a gas inlet communicating with an interior of the heater; and
a gas discharge outlet communicating with the interior of the heater,
wherein the gas inlet is located closer to the other opening of the heater than the second graphite pipe is as determined along an axial direction of the heater, and
the gas discharge outlet is located between the second graphite pipe and the push-in device as determined along the axial direction of the heater.

**3.** The heat treatment apparatus according to claim 2, further comprising: an insulating material covering a periphery of the heater,
wherein the discharge outlet is located in an area covered with the insulating material.

**4.** The heat treatment apparatus according to any one of claims 1 to 3, further comprising: a plurality of temperature sensors for measuring a temperature of the heater.

Fig.1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21B
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21D
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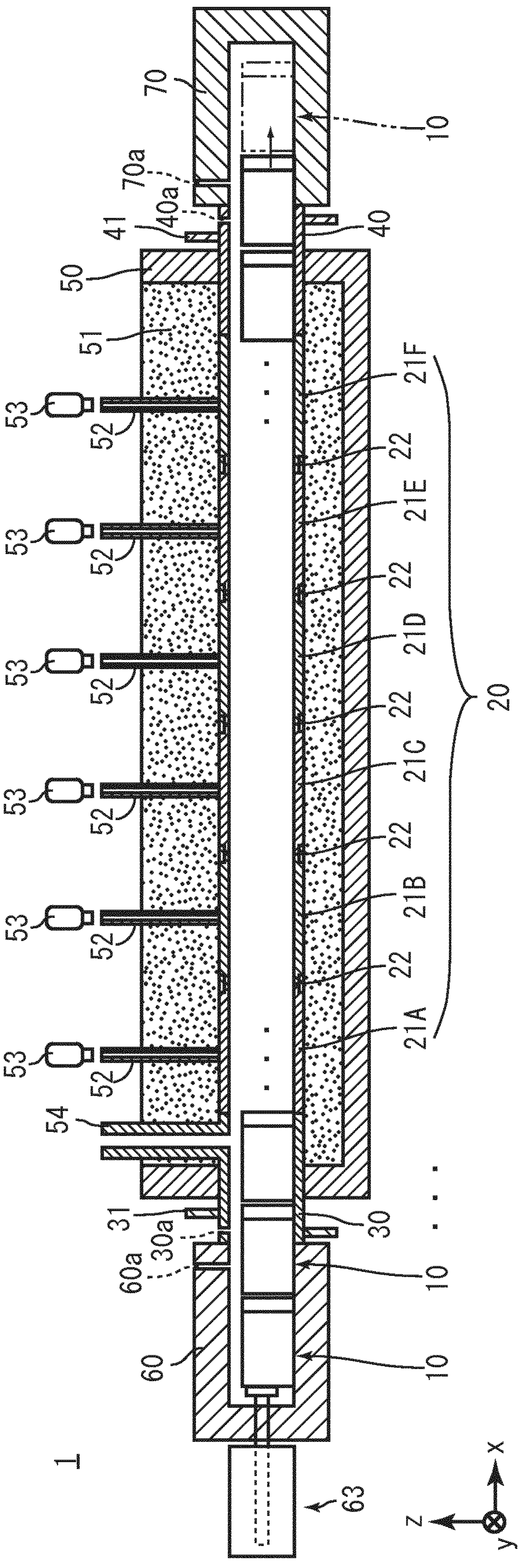
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21C
21D
21E
21F
22
30
30a
31
40
40a
41
50
51
52
53
54
60
60a
63
70
70a
x
y
z

*Fig.2*

Fig.3

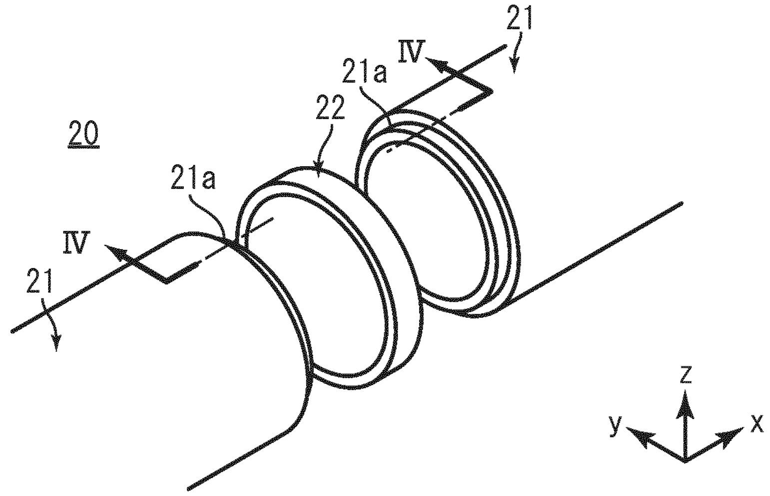



Fig.4

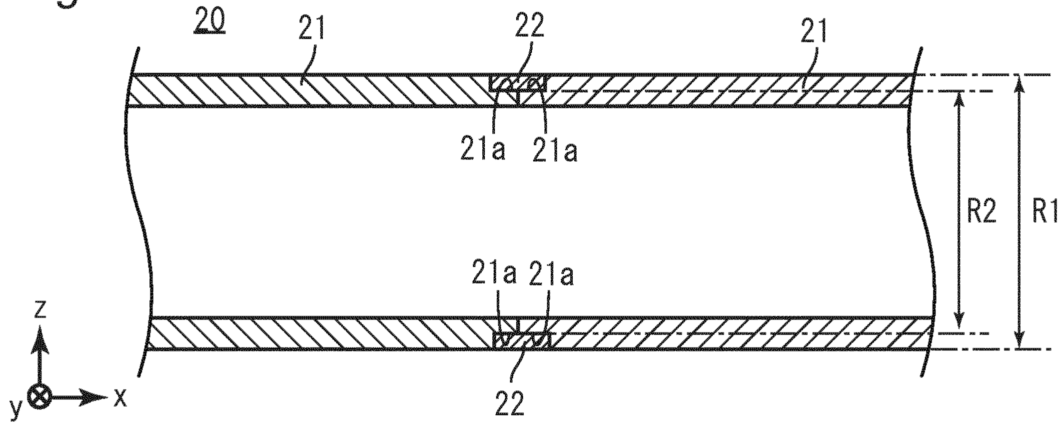



Fig.5

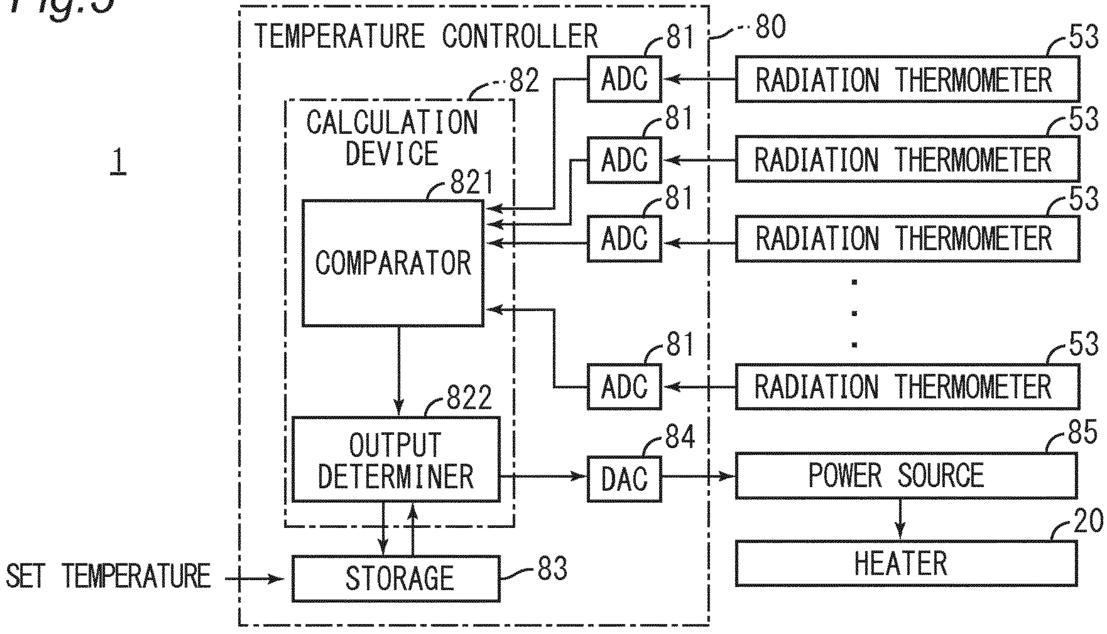


*Fig.6*

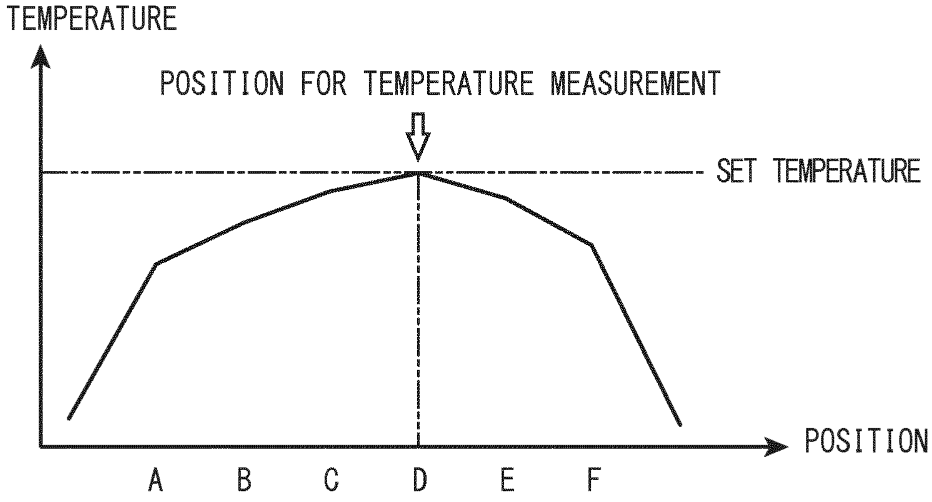



*Fig.7*

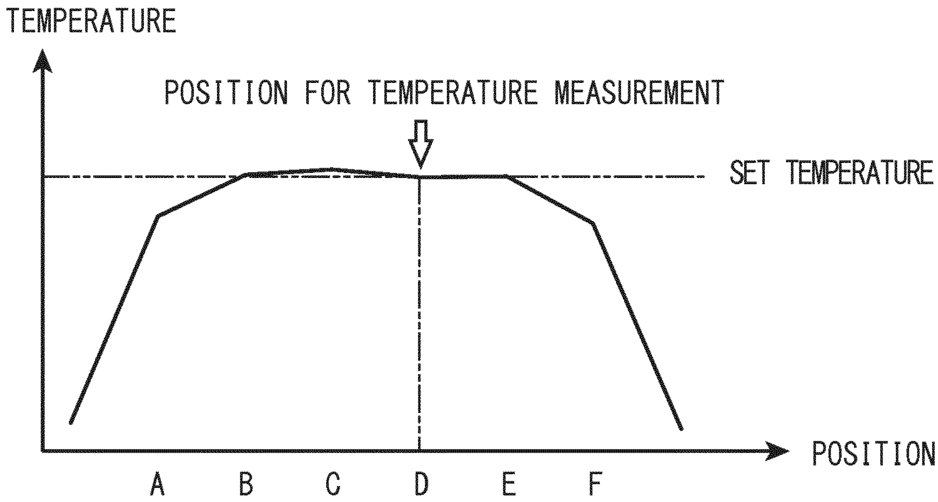
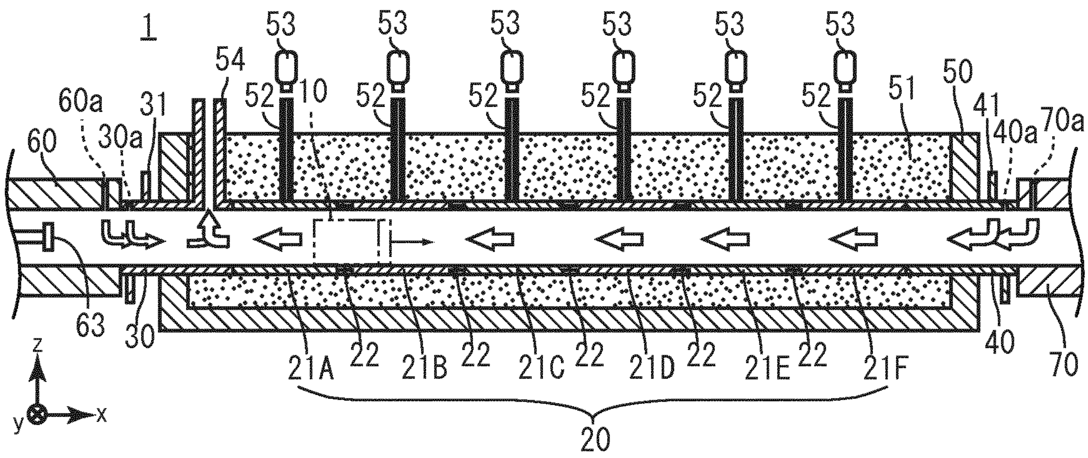



*Fig.8*



**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2016/051604

A. CLASSIFICATION OF SUBJECT MATTER
*F27B9/36*(2006.01)i, *F27D11/02*(2006.01)i, *H05B3/00*(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)
F27B9/00-9/40, F27D7/00-15/02, H05B1/00-3/00

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 | 1996-2016 |
| Kokai Jitsuyo Shinan Koho | 1971-2016 | Toroku Jitsuyo Shinan Koho | 1994-2016 |

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. |
|---|---|---|
| A | JP 2000-211909 A (SEC Corp.), 02 August 2000 (02.08.2000), (Family: none) | 1-4 |
| A | JP 8-198612 A (SEC Corp.), 06 August 1996 (06.08.1996), (Family: none) | 1-4 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 14 April 2016 (14.04.16) | 26 April 2016 (26.04.16) |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| Japan Patent Office<br>3-4-3,Kasumigaseki,Chiyoda-ku,<br>Tokyo 100-8915,Japan | Telephone No. |

Form PCT/ISA/210 (second sheet) (January 2015)

## REFERENCES CITED IN THE DESCRIPTION

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### Patent documents cited in the description


- JP 2002069757 A **[0004]**
- JP 2744617 B **[0004]**
- JP 3787241 B **[0005]**