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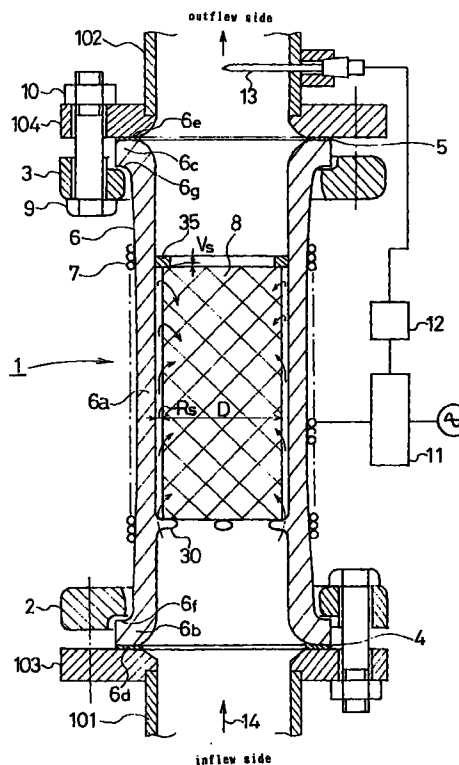
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(54) ELECTROMAGNETIC INDUCTION HEATER AND OPERATION METHOD THEREFOR

(57) An electromagnetic induction heater which is provided with a silicon nitride pipe (6 or 41) of a non-magnetic material through which a liquid flows in and out, a coil (7) wound around the silicon nitride pipe (6 or 41), and a heating body (8) accommodated in the silicon nitride pipe (6 or 41) and heated by electromagnetic induction by the coil (7), and which has flange members (2, 3) so formed at both ends of the silicon nitride pipe (6 or 41) as to engage with the end portions of the silicon nitride pipe (6 or 41) and to protrude outward in a radial direction, metal pipes (101, 102) having flanges (103, 104) and connected to both ends of the silicon nitride pipe (6 or 41), and fastening members (9, 10) for fastening the flange members (2, 3) at both ends of the silicon nitride pipe (6 or 41) to the flanges (103, 104) of the metal pipes (101, 102), respectively. The operation method comprises bringing the inside of the pipe into the immersed state by a fluid before the fluid is passed through the pipe, preheating the heating body (8) inside the pipe by electromagnetic induction, and allowing the fluid to flow.

Fig. 1



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Description

Technical Field

The present invention relates to an electromagnetic induction heater, of good response, for heating a heating element immersed in a fluid such as a liquid and a gas by means of electromagnetic induction heating so that the fluid can be heated by direct heat transfer, and to an operation method thereof.

Background Art

For heating a fluid such as a liquid or a gas, a heat exchanger is generally used. For instance, a sheathed heater is powered to heat a thermal oil, for performing heat exchange between a heating medium and the fluid by use of the heat exchanger.

This indirect heating system using the heat exchanger needs to heat the heating medium, first, and thus it takes much rise time, and as such had a tendency to upsize the heater. Accordingly, a direct heating system of an electromagnetic induction heater has been proposed, as disclosed by Japanese Laid-open Patent Publication No. Hei 3(1991)-98286 and others, according to which a pipe for a fluid to pass through is formed of a nonmagnetic material such as an insulating material, and a heating element immersed in a fluid accommodated in the pipe is heated by means of electromagnetic induction. This direct heating system of electromagnetic induction heater enables an efficiency of heat transfer from the heating element to the fluid to be increased to about 90% by, for example, enlarging a heating area of the heating element immersed in the fluid, and also enables the response to be enhanced.

However, the electromagnetic induction heater proposed by Japanese Laid-open Patent Publication No. Hei 3(1991)-98286 and others is so small in size as to cause a localized heating, and as such can allow a partial thermal stress to be easily generated in a pipe accommodating the heating element therein. In particular, the pipe accommodating the heating element therein is required to be formed of a non-magnetic material, for the reason of which a ceramic pipe is used for it, to allow for heat resistance and chemical resistance. The ceramic pipe is liable to crack in comparison with a metal pipe and thus is disadvantageously subject to limitations on operation conditions for high temperature heating and instantaneous heating.

To solve this problem, the present invention has been made, with the aim to provide an electromagnetic induction heater capable of preventing fracture and breakage of the pipe during high temperature heating and instantaneous heating, and the operating method thereof.

Disclosure of the Invention

An electromagnetic induction heater of the present invention designed to solve the abovesaid problem comprises a pipe made of non-magnetic material through which a fluid flows in and out, a coil wound around the pipe, and a heating element accommodated in the pipe to be heated by means of electromagnetic induction caused by the coil, said pipe being a molded form of silicon nitride. The silicon nitride used should be resistant to thermal shock at temperatures exceeding 600°C. It is particularly preferable to use the silicon nitride resistance to the thermal shock at temperatures exceeding 800°C. The silicon nitride (Si_3N_4), which is a kind of non-oxide ceramic and a non-magnetic material, has a good corrosion resistance to acid and alkali and is superior to silicon carbide of the same series in flexural strength, fracture toughness and thermal shock resistance. In particular, resistance to the thermal shock at high temperatures of 400°C or more to 800°C or less can be attained by controlling the respective manufacturing processes of forming, sintering and finishing and by controlling the composition in an usual manner. Further, under the careful control of the manufacturing processes and the composition, resistance to the thermal shock at higher temperatures of 600°C or more to 800 °C or less can be attained. Though even this thermal resistance temperature range is about three times or more as high as that of the mold of alumina, resistance to the thermal shock at even higher temperatures exceeding 800°C or 880°C can be attained by making specific preparation of the manufacturing processes and the composition, to endure the high temperature heating in a considerably wide temperature range and the instantaneous heating.

It is noted that the term of "the thermal shock resistance temperature" used herein is intended to mean a specified maximum temperature until which, when a test piece of $3 \times 4 \times 35\text{mm}$ required by JIS R1601 is heated at a specified temperature for 15 minutes and then is immersed into water of 20-25°C, the flexural strength after the immerse in water does not become inferior to the flexural strength before the heating.

It is hard for silicon nitride (Si_3N_4) to be joined to a metal pipe and the like by means of heat fusion. Further, it is difficult for silicon nitride to be formed into a desired shape. So, if flange portions are integrally formed with the silicon nitride pipe at the opposite ends or if a supporting portion for supporting the heating element is integrally formed in the silicon nitride pipe, that entails high costs.

Accordingly, for arrangement in a metal pipe line of a chemical plant, for example, the electromagnetic induction heater of the present invention may further comprise flange members including flanges, formed at opposite ends of the silicon nitride pipe, to engage with the ends of the silicon nitride pipe and project radially outwardly therefrom; metal pipes having flanges to be

connected to the opposite ends of the silicon nitride pipe; and fastening members for fastening the flange members at the opposite ends of the silicon nitride pipe to the flanges of the metal pipes, respectively.

Further, at least one of the metal pipes may be provided with an expandable portion which is on an extension of an axis of the silicon nitride pipe and is expandable at least in the axial direction.

Additionally, the at least one metal pipe may be provided with a supporting member for supporting from the metal pipe the heating element in said pipe.

The provision of the flange members engageable with the ends of the silicon nitride pipe and the supporting member for supporting the heating element in the silicon nitride pipe can eliminate the need for forming the flange portions and the heating element supporting portion in the silicon nitride pipe, to simplify the shape of the silicon nitride pipe. Thus, the molding of the silicon nitride pipe can be facilitated and manufacturing costs can be reduced. In addition, the flange members engageable with the ends of the silicon nitride pipe can facilitate the connection between the metal pipe and the silicon nitride pipe.

Further, the expandable portion disposed on at least one of the metal pipes can allow thermal expansion of the silicon nitride pipe to adequately escape in the axial direction, to prevent breakage of the silicon nitride pipe due to the thermal expansion.

Also, an operation method of the present invention, using an electromagnetic induction heater comprising a pipe made of a non-magnetic material through which a fluid flows in and out; a coil wound around the pipe; and a heating element accommodated in the pipe to be heated by means of electromagnetic induction caused by the coil, the pipe being a molded form of silicon nitride, comprises filling the pipe with fluid before the fluid is allowed to flow; and preheating the heating element in the pipe by means of the electromagnetic induction before the fluid is allowed to flow.

The silicon nitride used is to be resistant to thermal shock at temperatures exceeding 600°C, preferably, exceeding 800°C. Even when the pipe heated by preheating of the heating element is cooled down suddenly by allowing the before-heating fluid to pass through the pipe, the pipe can endure such thermal shock because of its resistance to thermal shock at temperatures exceeding 600°C.

Further, the operation method of the electromagnetic induction heater according to the present invention is suitable in the case of the fluid being gas. Since gas is small in heat capacity, it can be heated rapidly from room temperature to high temperature. Even when the gas of room temperature is allowed to flow through the pipe after the heating element is preheated to high temperature, the pipe which is made of silicon nitride resistant to thermal shock at high temperatures enables the gas to flow with high temperature from the beginning.

As described above, the electromagnetic induction

heater of the present invention uses the silicon nitride excellent in thermal shock resistance as a material of the pipe and thus has the characteristic of high responsiveness. Through the use of this characteristic, there is provided the advantageous effect that no operation condition limitations stemming from the thermal shock are provided by high temperature heating or instantaneous heating, thus providing wide-ranging operation conditions for the heating.

The operation method of the electromagnetic induction heater according to the present invention can provide the result that through the use of the improved resistance to thermal shock, the zero-start that the fluid is allowed to flow, with the heating element preheated, to thereby produce the fluid of required temperature from the beginning of flowing can be attained. Further, the operation method of the electromagnetic induction heater according to the present invention can provide the result that the zero-start can be applied for the heating of gas requiring a particularly high temperature heating.

Brief Description of the Drawings

FIG. 1 is a longitudinal sectional view of an electromagnetic induction heater of an embodiment of the present invention; FIG. 2(a) and FIG. 2(b) are structural views of a heating element used in the electromagnetic induction heater of an embodiment of the present invention: FIG. 2(a) being a top view showing the structure of the heating element and FIG. 2(b) being a perspective view showing the structure of the heating element; and FIG. 3 is a longitudinal view of the electromagnetic induction heater of another embodiment of the present invention.

Best Mode For Carrying Out the Invention

An exemplary mode for carrying out the invention will be given below with reference to the accompanying drawings. FIG. 1 is a longitudinal sectional view of an electromagnetic induction heater; FIG. 2(a) and FIG. 2(b) are the structural views of a heating element used in the electromagnetic induction heater.

In FIG. 1, the electromagnetic induction heater 1 is mainly composed of flange members 2, 3, a silicon nitride pipe 6, a coil 7 and a heating element 8. The electromagnetic induction heater 1 is arranged at some midpoint in a metal pipe line 101, 102 of, for example, a chemical plant and the like so that a fluid 14 may flow from a downstream side to an upstream side of FIG. 1. A power unit 11 is commonly connected to the coil 7 of the electromagnetic induction heater 1 or the coils 7 of a plurality of electromagnetic induction heaters 1. A control unit 12 is connected to the power unit 11, and a temperature sensor 13 is connected with the control unit 12, to form a heating system.

The silicon nitride pipe 6 is manufactured in one

piece so that flange portions 6b, 6c can be located at opposite ends of a body 6a. The manufacturing process includes the steps of molding, sintering and processing. The molding step includes an injection molding and a slip casting; the sintering step includes a sintering method under pressure of choke damp by which decomposition of silicon nitride is restrained while much use is made of high temperature; and the processing includes an electrical discharge machining and laser beam machining. Specifically, the silicon nitride pipe is formed into a specified form by molding silicon nitride into an illustrated pipe form by the injection molding or equivalent; sintering the molded form by the sintering; and machining a working face and the like by the electrical discharge machining or equivalent.

In this process, the composition of the silicon nitride and the manufacturing process are so controlled that the silicon nitride pipe 6 can be resistant to thermal shock at temperatures of 400°C or more to 800°C or less, preferably, 600°C or more to 800°C or less.

The body 6a is so manufactured as to have a required inner diameter and a required wall thickness. The flanges 6b, 6c at both ends of the body are formed by expanding the periphery of the body at the ends to a necessary and minimum extent, to form thereon working surfaces 6d, 6e to packing 4, 5 and catching portions 6f, 6g to the flange members 2, 3.

The flange members 2, 3 are engaged with end portions of the silicon nitride pipe 6 to form radially projecting flanges at the opposite ends of the silicon nitride pipe 6. The flanges are so structured as to be divided into two: for example, the flanges are divided into two half-round segments, which are hinged together to be opened and closed and are held in their closed state by fixing means. The flange members 2, 3 have holes for bolts to pass through, which are circumferentially spaced at an uniform interval, so that the bolts inserted in the holes can extend in parallel to an axial dimension of the silicon nitride pipe 6 with their loosely fitted onto the body 6a.

With holding the flanges 6b, 6c of the silicon nitride pipe 6, the flange members 2, 3 are fastened to flanges 103, 104 at the ends of the metal pipe lines 101, 102 via fastening means such as bolts 9 and nuts 10. The working surfaces 6d, 6e of the flanges 6b, 6c are then brought into intimate contact with related working surfaces of the flanges 103, 104 through the packing 4, 5, to accomplish both the seal and the joint. It is difficult for silicon nitride (Si_3N_4) to be joined to the metal pipe or equivalent by means of heat fusion. The flange members 2, 3 engageable with the ends of the silicon nitride pipe can facilitate the connection between the metal pipes and the silicon nitride pipe.

Austenite base stainless steel, such as SUS 316 of a non-magnetic material, is used as a material of the flange members 2, 3, so as to be resistant to the magnetic flux produced by the coil 7. The temperature sensor 13 is fixed to the metal pipe line 102 at the discharge

side of the fluid 14 via a socket.

The heating element 8 is accommodated in the silicon nitride pipe 6, around which the coil 7 is wound at a position opposite to the heating element 8. The coil 7 used is made of lowest possible copper loss and is formed by a twined litz wire or a copper tube of round, half-round or oval.

Preferably, the heating element 8 has permeability with a degree that permits a supply of power without difficulty; capability of facilitating the heat exchange from and to the fluid 14; and corrosion resistance to the fluid 14. Martensitic stainless steels, such as SUS 447J1, are used as a material of the heating element. Further, the detailed structure of the heating element 8 is described with reference to FIG. 2. FIG. 2(a) is a top view showing the structure of the heating element 8 and FIG. 2(b) is a perspective view showing the structure of the heating element 8.

The heating element 8 is formed into a cylindrical column shape as a whole, with first plate-like sheet materials 21 and second corrugated sheet materials 22 laminated alternately and also the first sheet materials 21 positioned at both ends of the side surfaces. The sheet materials are so arranged that wave crests (or wave troughs) 23 of the second sheet materials 22 are just slanted at an angle α with respect to the center axis 24 and the wave crests (or troughs) 23 of second sheet materials 22 adjoining across the first sheet materials 21 are intersected each other. At the intersecting points 25 of the crests (or troughs) 23 of the second adjoining sheet materials 22, the first sheet materials 21 and the second sheet materials 22 are welded by spot welding, for electrical conduction. The second sheet materials 22 have, on their surfaces, holes 26 for causing turbulent flow of the fluid 14. In place of or in addition to the holes 26, satinizing may be effectively given to the first sheet materials 21 and/or the second sheet material 22 to roughen the surfaces of the same. In short, the first sheet materials 21 and the second sheet materials 22 are arranged to be substantially parallel to each other with respect to a direction of the diameter D passing through the center axis 24 of the heating element 8 (a transverse direction of the periphery) so that electric flow can be most facilitated. Then, a skin effect (a state in which only an outer periphery of the heating element 8 is heated) appearing in the electromagnetic induction is broken to heat the interior of the heating element 8.

The heating element 8 originally formed has such a diameter D as to define an annular space Rs between its outer periphery and an inner periphery of the silicon nitride pipe 6. The heating element 8 is loosely fitted into the silicon nitride pipe 6 to be in axial alignment with it and is inserted in the pipe 6 until it is held in place by projecting portions 30 serving as holding means. The diameter D of the heating element 8 is determined so that when the fluid 14 is heated by the apparatus 1, the annular space Rs, which is larger than a thermal expansion difference between the amount by which the silicon

nitride pipe 6 thermally expands in the radial direction and the amount by which the heating element 8 thermally expands in the radial direction, is defined between the heating element 8 and the silicon nitride pipe 6. The projecting portions 30 serving as the holding means are spaced from each other circumferentially so that the fluid from the inflow side can flow into the annular space Rs. Instead of the projecting portions 30, a ceramic ring, having a number of holes or notches communicating with the annular space Rs, of non-magnetic and good heat resistance and corrosion resistance, may be press-fitted in the pipe.

35 denotes a ring stopper, which is made of a material of non-magnetic and good heat resistance and corrosion resistance, such as ceramic. The ring stopper is fitted into the silicon nitride pipe 6 from the discharge side of the fluid 14 and is fixed in place, with a space Vs, of equal to or slightly short of the thermal expansion amount of the heating element 8 in the axial direction, defined between the stopper and the heating element 8. The ring stopper 35 is set from the discharge side to be positioned over the heating element 8, extending radially across the annular space Rs, and is brought into engagement with the heating element 8 via the thermal expansion of the heating element 8 to close the annular space Rs from the discharge side.

In operation, when the fluid 14 is allowed to flow from the inflow side to the discharge side of the apparatus 1 and is heated through the silicon nitride pipe 6 and the heating element 8 by means of the electromagnetic induction caused by the coil 7, there arises a difference in radial thermal expansion between the silicon nitride pipe 6 and the heating element 8. The annular space Rs, which is defined between the silicon nitride pipe 6 and the heating element 8 and is sufficient to allow for the thermal expansion difference, then absorbs the thermal expansion difference, with narrowing the annular space Rs, so as to prevent stress from exerting on the silicon nitride pipe 6 when the heating element 8 contacts with and presses on it. Also, the heating element 8 thermally expands in the axial direction as well, the thermal expansion of which is however absorbed by the thermal expansion of the space Vs formed between the heating element 8 and the ring stopper 35.

During the time, the fluid 14 flowing from the metal pipe line 101 into the inflow side of the apparatus 1 flows into the heating element 8 to be heated therein and then flows out to the discharge side, and a part of the fluid 14 tries to flow from the inflow side to the discharge side directly or by way of the heating element 8 and the annular space Rs. On the other hand, the heating element 8 is thermally expanded in the axial direction and is brought into engagement with the ring stopper 35 to close the annular gap Rs at the discharge side, so as to hinder the part of the fluid 14 from flowing directly to the discharge side. As a result, a pressure to force the fluid into the discharge side is generated in the annular space Rs by the flow of the fluid 14 from the

inflow side, and as such can allow the fluid 14 flowing into the annular space Rs to be forced into the heating element 8 by the pressure.

This enables a possible breakage of the silicon nitride pipe 6 caused by the thermal expansion of the heating element 8 to be prevented even when the heating element 8 is heated by means of the electromagnetic induction caused by the coil 7. Also, even when there is formed the annular space Rs for allowing the thermal expansion of the heating element 8 to be absorbed, since the heating element 8 is thermally expanded to be brought into engagement with the ring stopper 35 and thereby the annular space Rs is closed from the discharge side to force the fluid 14 flowing into the annular gap Rs into the heating element 8, the fluid 14 can be heated uniformly by the heating element 8.

Next, an operation method for heating the fluid by use of the above-mentioned electromagnetic induction heater 1 is discussed below. The method in which the heating element 8 is started to be heated by means of the electromagnetic induction while the fluid 14 is allowed to flow may be adopted, but such a method has a disadvantage that the fluid 14 is kept on flowing with its temperature remaining out of required temperature until it reaches the required temperature. According to the present invention, good responsivity of the electromagnetic induction heater 1 is used to enable the zero-start that the fluid is allowed to flow with the temperature close to a required temperature from the beginning. First, the fluid is filled in the silicon nitride pipe 6 to dip the heating element 8 in the fluid. With kept in this state, the heating element 8 is heated by means of the electromagnetic induction, then allowing the heating element 8 and the fluid to be heated up to the required temperature. When the fluid is allowed to flow after that, the fluid can start flowing with the temperature close to the required temperature from the beginning, due to the good responsivity of the heating element 8.

At this time, the silicon nitride pipe is also heated to the same extent, so that, when the before-heated fluid flows into the heated silicon nitride pipe 6, the silicon nitride pipe 6 in the high temperature state is suddenly cooled down and subjected to the thermal shock. However, since the pipe is formed of silicon nitride of good thermal shock resistance capable of enduring temperatures ranging from 400°C or more to 800°C or less, the pipe can endure the thermal shock.

In the case of the fluid being gas, in particular, there may be cases where the pipe is heated up to temperatures as high as 600°C, sometimes 800°C or more, in the case of which the degree of the thermal shock to the pipe increases. The pipe manufactured can however be allowed to have the thermal shock resistance at temperatures exceeding 880°C by particularly controlling the composition of the silicon nitride and the manufacturing process. In the case of the silicon nitride of EC-141 (Type number) available from Nippon Tokushu Togyo K.K., for instance, the thermal shock resistance temper-

ature exceeds 880°C. By using the silicon nitride capable of allowing the pipe to have such high thermal shock resistance temperature for the pipe, the pipe is allowed to have the capability to endure the thermal shock even when the above-mentioned zero-start is repeated.

Next, the electromagnetic heater of another embodiment of the present invention will be described with reference to Fig. 3 in which the same reference numerals identify the same elements of function in FIG. 1, with the description thereof omitted.

The difference between FIG. 3 and FIG. 1 is in that the metal pipe 102 on the discharge side of the fluid is provided with an expandable portion 40, and the metal pipes 101, 102 located on the inflow side and the discharge side of the fluid are respectively provided with first and second supporting members 42, 43 for supporting from the metal pipes the heating element 8 in the silicon nitride pipe 41. Thus, the silicon nitride pipe 6 of this embodiment is not provided therein with any projecting portions 30 used as the holding means for holding the heating element 8, differently from the silicon nitride pipe 6 of FIG. 1, but is simply formed into a cylindrical shape with its outer periphery at the both ends slightly expanded.

The expandable portion 40 of the metal pipe 102 is axially expandable, for allowing the thermal expansion of the silicon nitride pipe 41 to escape in the axial direction properly to prevent the silicon nitride pipe 41 from being damaged by the thermal expansion. From the viewpoint that the thermal expansion of the silicon nitride pipe 41 is allowed to escape axially with efficiency, the expandable portion 40 is preferably arranged at the nearest possible position to the silicon nitride pipe 41. According to this embodiment, the expandable portion 40 is arranged in proximity to the flange 104 near a joint portion between the silicon nitride pipe 41 and the metal pipe 102.

Alternatively, the expandable portion, axially expandable and contractable, may be arranged at least somewhere on an extension of the axis of the silicon nitride pipe to allow the thermal expansion of the silicon nitride pipe to escape in the axial direction properly. For example, the expandable portion, even if arranged at a position about 1 meter away from the silicon nitride pipe, can prevent breakage of the silicon nitride pipe caused by the thermal expansion.

The expandable portion 40, which is arranged only in the metal pipe 102 at the discharge side of the gas in this embodiment, may be arranged in both of the metal pipe 101 at the inflow side of the gas and the metal pipe 102 at the discharge side of the gas, if desirable. Alternatively, the expandable portion 40 may be arranged only in the metal pipe 101 at the inflow side of the gas.

The expandable portion 40 comprises outer pipes 102a, 102b of the metal pipe 102; an inner sliding pipe 40a which is so arranged in the outer pipes 102a, 102b as to be in contact with the inner periphery thereof, a bellows 40b secured between the outer pipes 102a,

102b and covering the outer periphery of the inner sliding pipe 40a; and a coupling member 40c for coupling the outer pipes 102a, 102b with each other so that the outer pipe 102a is axially movable relative to the outer pipe 102b.

The coupling member 40c is a cylindrical member receiving the outer pipes 102a, 102b therein and having a plurality of axially extending elongate slits 50. With the outer pipe 102b inserted in the coupling member 40c at one end thereof to be fixed thereto and the outer pipe 102a inserted in coupling member at the other end thereof, pins 51 which are so fitted in the slits 50 as to be slidable along the axial direction thereof are secured to the outer pipe 102a.

When the silicon nitride pipe 41 is expanded by heat, the outer pipe 102a moves along the outer periphery of the inner sliding pipe 40a, and the bellows 40b expands or contracts in response to the movement of the outer pipe 102a.

The structure using the bellows may be modified such that a pleated pipe joint having pleats through which the pipe is allowed to expand axially is used as the expandable portion 40. With this modification, not only axial expansion but also axial displacement occurring when the silicon nitride pipe is incorporated in the metal pipe lines can be absorbed.

The first supporting member 42 comprises a first projection 42a extending from the inner periphery of the metal pipe 102 to the center of the diameter of the pipe; a first column 42b extending axially from a projected terminal of the first projection 42a to the ring stopper 35; and a beam 42c extending radially from the ring stopper 35 of the first column 42b to extend across the ring stopper 35.

The first projection 42a of the first supporting member 42, which is fixed in the metal pipe 102 by welding or equivalent, is preferably made of the same material as that of the metal pipe 102. The first column 42b of the first supporting member 42, which may be molded to be integral with or may be joined to the first projection 42a by welding, adhesive bonding, bolting and the like, may be made of the same material as the metal pipe or ceramic such as silicon nitride, preferably, non-magnetic ceramic, in order to be hardly affected by magnetic flux produced by the coil 7.

The first supporting member 42 is fixed in position, with the beam 42c being so positioned as to be in touch with the ring stopper 35. The first supporting member 42 is secured in the metal pipe 102 by the first projection 42a being fixed on the inner periphery of the metal pipe 102 by welding or other suitable means. This enables the heating element 8 to be kept in position in the silicon nitride pipe 41 without causing the ring stopper 35 to be out of position even when flow velocity of the fluid in the pipe increases.

The second supporting member 43 comprises a second projection 43a extending from the inner periphery of the metal pipe 101 to the center of the diameter of

the pipe and a second column 43b extending axially from a projected terminal of the second projection 43a to the heating element 8.

The materials of the second projection 43a and the second column 43b of the second supporting member 43 are the same as those of the first projection 42a and the first column 42b of the first supporting member 42.

The second supporting member 43 is fixed in position, with one end of the second column 43b being so positioned as to be in touch with the heating element 8. The second supporting member 43 is secured in the metal pipe 101 by the second projection 43a being fixed on the inner periphery of the metal pipe 101 by welding or other suitable means. This enables the heating element 8 to be kept in position in the silicon nitride pipe 41, in association with the first supporting member, thus eliminating the use of the projecting portions 30 as the holding means for holding the heating element 8, as in the silicon nitride pipe 6 shown in FIG. 1.

As mentioned above, the flange members 2, 3 engageable with the ends of the silicon nitride pipe 41 and the first and second supporting members 42, 43 for supporting the heating element 8 in the silicon nitride pipe from the metal pipes 101, 102 can eliminate the need for forming the flange portions and the heating element supporting portions at the silicon nitride pipe. As a result of this, the form of the silicon nitride pipe is simplified, as shown in FIG. 3, to facilitate the mold of the silicon nitride pipe and reduce the manufacturing costs.

Capability of Exploitation in Industry

As obvious from the foregoing, the present invention is optimally applicable to an electromagnetic induction heater capable of preventing the pipe from being damaged when heated at high temperatures or instantaneously, and to the operation method thereof.

Claims

1. An electromagnetic induction heater comprising a pipe (6 or 41) made of a non-magnetic material through which a fluid flows in and out; a coil (7) wound around said pipe (6 or 41); and a heating element (8) accommodated in said pipe (6 or 41) to be heated by means of electromagnetic induction caused by said coil (7), said pipe (6 or 41) being a molded form of silicon nitride.
2. An electromagnetic induction heater as set forth in Claim 1, wherein thermal shock resistance temperature of said silicon nitride exceeds 600°C.
3. An electromagnetic induction heater as set forth in either of Claims 1 and 2, which comprises:

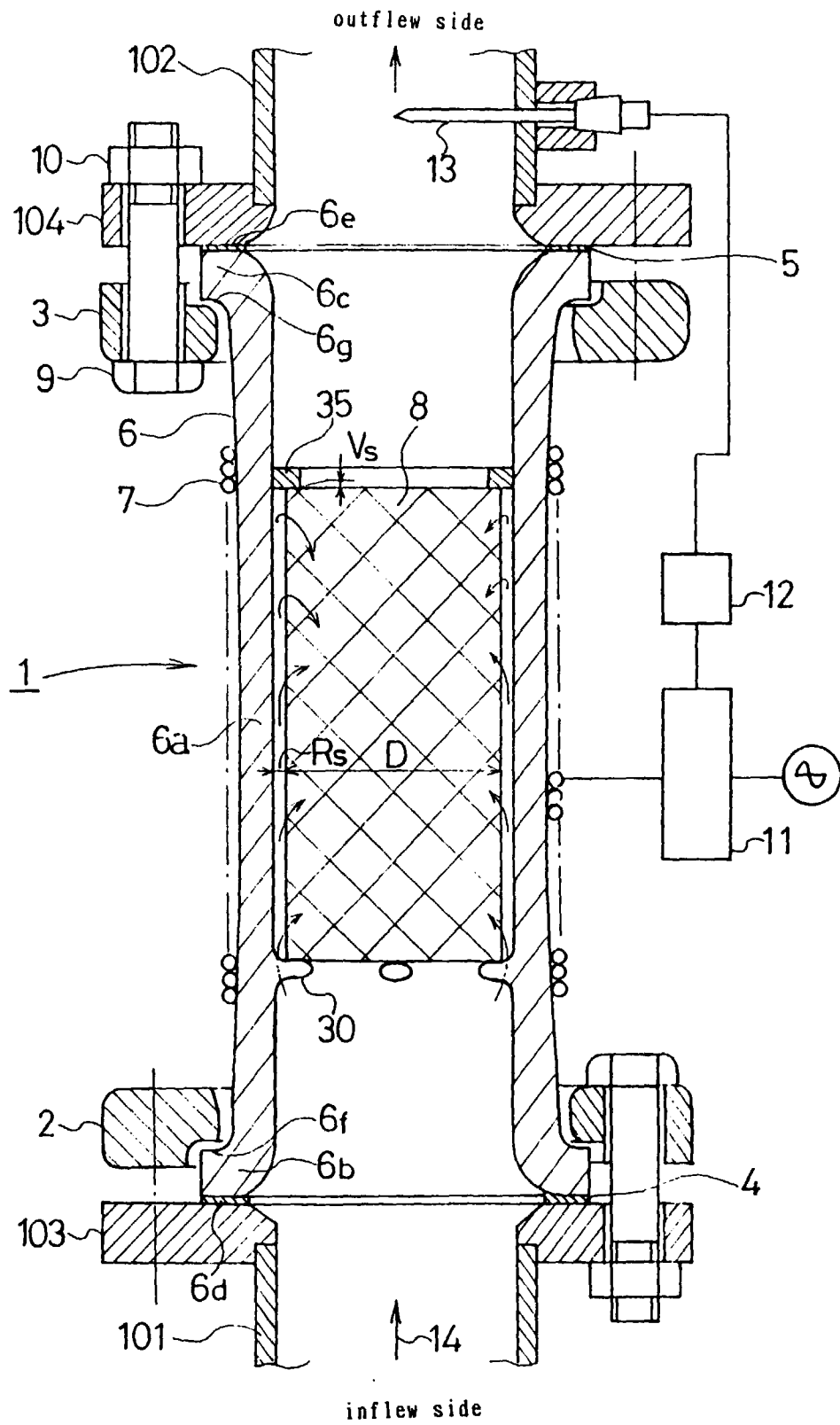
flange members (2, 3) including flanges, formed at opposite ends of said silicon nitride

pipe (6 or 41), to engage with the ends of said silicon nitride pipe (6 or 41) and project radially outwardly therefrom;

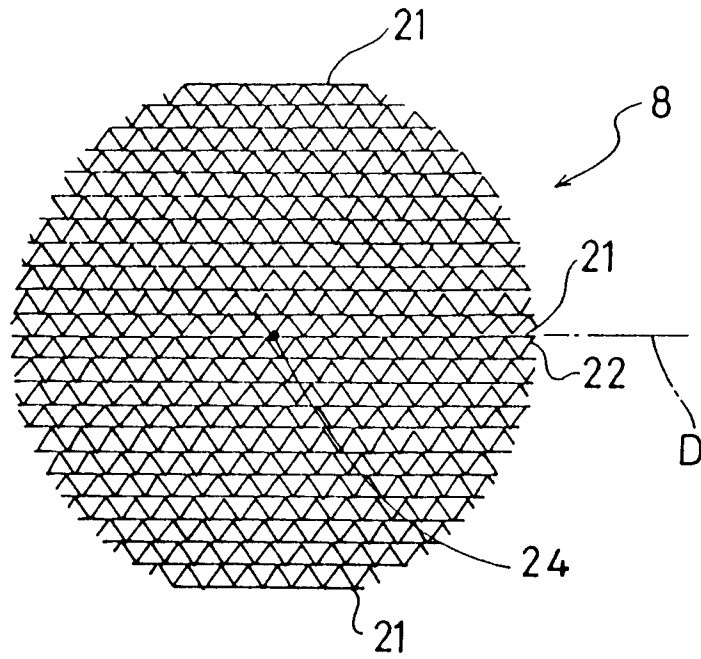
metal pipes (101, 102) having flanges (103, 104) to be connected to said opposite ends of said silicon nitride pipe (6 or 41); and fastening members (9, 10) for fastening said flange members (2, 3) at the opposite ends of said silicon nitride pipe (6 or 41) to said flanges (103, 104) of said metal pipes (101, 102), respectively.

4. An electromagnetic induction heater as set forth in Claim 3, wherein at least one of said metal pipes (101, 102) is provided with an expandable portion (40) which is on an extension of an axis of said silicon nitride pipe (6 or 41) and is expandable at least in the axial direction.
5. An electromagnetic induction heater as set forth in Claim 4, wherein said metal pipes (101, 102) are provided with supporting members (42, 43) for supporting said heating element (8) in said silicon nitride pipe (41).
6. An operation method using an electromagnetic induction heater comprising a pipe (6 or 41) made of a non-magnetic material through which fluid flows in and out; a coil (7) wound around said pipe (6 or 41); and a heating element (8) accommodated in said pipe (6 or 41) to be heated by means of electromagnetic induction caused by said coil (7), said pipe (6 or 41) being a molded form of silicon nitride, said operation method comprising: filling said pipe (6 or 41) with fluid before the fluid is allowed to flow; and preheating said heating element (8) in said pipe (6 or 41) by means of the electromagnetic induction before the fluid is allowed to flow.
7. An operation method of said electromagnetic induction heater as set forth in Claim 6, wherein thermal shock resistance temperature of said silicon nitride exceeds 600°C.
8. An operation method of said electromagnetic induction heater as set forth in either of Claims 6 and 7, wherein said fluid is gas.

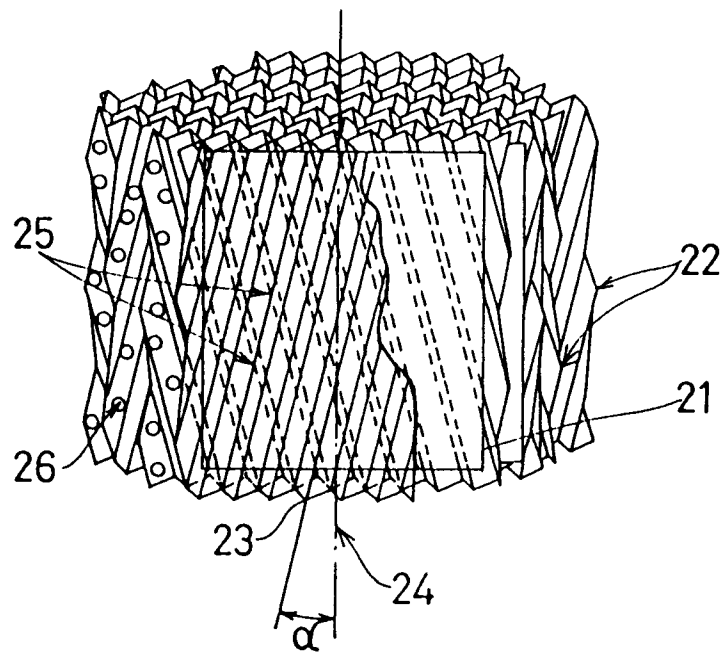
F i g . 1



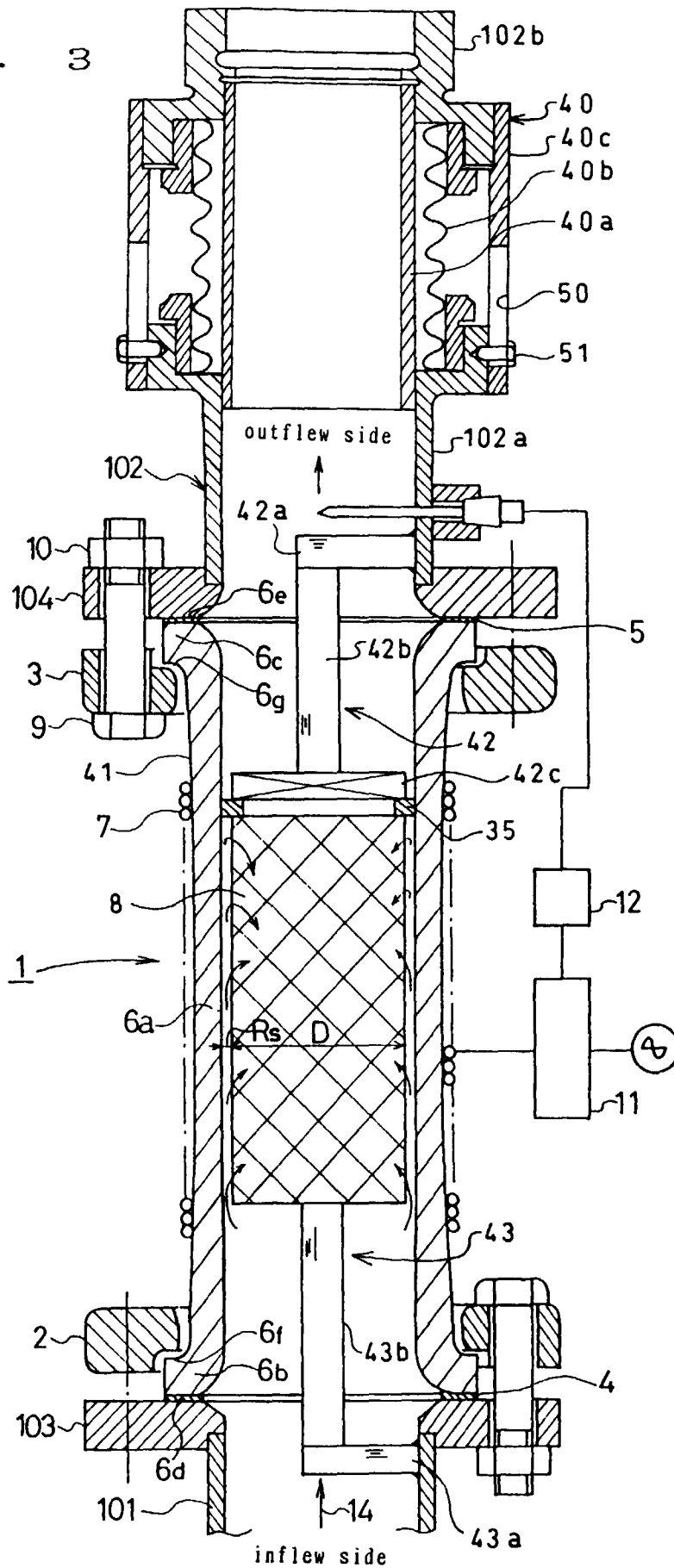
F i g . 2 (a)



F i g . 2 (b)



F i g . 3



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP96/02166

A. CLASSIFICATION OF SUBJECT MATTER Int. Cl ⁶ H05B6/10 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) Int. Cl ⁶ H05B6/10, F24H1/10 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Kokai Jitsuyo Shinan Koho 1971 - 1995 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.
Y	JP, 7-35413, A (Seta Giken K.K.), February 7, 1995 (07. 02. 95) (Family: none)	1 - 8
Y	JP, 53-146343, A (Hitachi, Ltd.), December 20, 1978 (20. 12. 78), Page 4, lower left column, line 18 to lower right column, line 5; Fig. 6 (Family: none)	1 - 8
Y	JP, 63-190280, A (Toshiba Corp.), August 5, 1988 (05. 08. 88), Page 2, upper right column, lines 8 to 18; Fig. 2 (Family: none)	1 - 8
Y	Microfilm of the specification and drawings annexed to the written application of Japanese Utility Model Application No. 56586/1989 (Laid-open No. 146794/1990) (Teijin Seiki Co., Ltd.), December 13, 1990 (13. 12. 90), Page 11, lines 2 to 16; Fig. 8 (Family: none)	3 - 5
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "I" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search September 17, 1996 (17. 09. 96)		Date of mailing of the international search report October 1, 1996 (01. 10. 96)
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