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(54) **Fusing roller assembly including a resistance coil for heating wound around a heat pipe roller for electrophotographic image forming apparatus**

Fixierrolleranordnung eines elektrophotographischen Bilderzeugungsgeräts mit Heizspule um eine Wärmeübertragungswalze

Ensemble de fixage avec la bobine de chauffage autour d'un tube de chauffe d'un appareil électrophotographique de formation d'images

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(56) References cited:
EP-A- 0 399 376 **WO-A-98/31194**
US-A- 6 072 979

- **PATENT ABSTRACTS OF JAPAN vol. 1997, no. 11, 28 November 1997 (1997-11-28) & JP 09 197863 A (MINOLTA CO LTD), 31 July 1997 (1997-07-31)**

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Description

[0001] The present invention relates to a fusing roller apparatus for an electrophotographic image forming apparatus, and more particularly, to a fusing roller apparatus for an electrophotographic image forming apparatus, which can be instantaneously heated with low power consumption.

[0002] In a general electrophotographic image forming apparatus such as a copy machine and laser beam printer, as an electrostatic charging roller adjacent to a photoreceptor drum rotates, a photosensitive material coated on the surface of the photoreceptor drum is uniformly charged. The charged photosensitive material is exposed to a laser beam scanned from a laser scanning unit (LSU) so that a latent electrostatic image is formed in a predetermined pattern on the photosensitive material. A developer unit supplies toner to the photosensitive material to develop the latent electrostatic image formed on the photosensitive material into a visible toner image. A predetermined transfer voltage is applied to a transfer roller which is put in contact with the photoreceptor drum at a predetermined force while the photoreceptor drum carries the toner image. In this state, as a print paper is fed in the gap between the transfer roller and the photoreceptor medium, the toner image formed on the photosensitive material is transferred to the print paper. A fixing unit which includes a fusing roller, instantaneously heats the print paper to which the toner image is transferred to fuse and fix the toner image to the print paper. In general, a halogen lamp is used as a heat source for the fixing unit. The halogen lamp is installed inside the fusing roller and heats the surface of the fusing roller to a target temperature with radiant heat.

[0003] In a conventional fusing roller apparatus of an electrophotographic image forming apparatus, which uses a halogen lamp as a heat source, the exterior surface of the fusing roller must generate heat; the fusing roller is therefore heated from the inside out by radiant heat from the halogen lamp. A pressure roller is located below the fusing roller. As paper carrying a toner image in a powder form passes between the fusing roller and the pressure roller, the paper is hot pressed by the predetermined force and the toner image is fused and fixed to the print paper by the heat and force from the fusing roller and the pressure roller.

[0004] A thermistor may be used for detecting and converting the surface temperature of the fusing roller into an electric signal and a thermostat may be used to cut off the power supply to the halogen lamp.

[0005] A conventional fusing roller apparatus which employs a halogen lamp as a heat source unnecessarily consumes a large amount of power, and needs a considerably long warm-up period when the image forming apparatus is turned on for image formation. In other words, after the application of power, a standby period follows until the temperature of the fusing roller reaches a target temperature, for example, for a few tens of seconds to a few minutes. I have found that with a conventional fusing roller apparatus, because the fusing roller is heated by radiant heat from the heat source, the rate of heat transfer is low. In particular, compensation for temperature variations due to a drop in the temperature of the heat roller caused by contact with a print paper is delayed, so that it is difficult to uniformly control the distribution of temperature along the axial length of the fusing roller. Even in a stand-by mode where the operation of the printer is suspended, power must be periodically applied so as to keep the temperature of the fusing roller constant, thereby causing unnecessary power consumption. Also, it takes a considerable amount of time to switch the fusing roller from its stand-by mode to an operating mode for image output, so that the resultant image cannot be rapidly printed.

[0006] An alternative design for a conventional fusing roller apparatus employs a heating plate placed in a lower portion of a flexible cylindrical film tube, with a pressure roller mounted underneath the heating plate. The film tube is rotated by a separate rotation unit and is locally heated and deformed at a part between the heating plate and the pressure roller. While this method of locally heating the film tube with a heating plate was thought to be advantageous in terms of low power consumption, it is unsuitable for high-speed printing.

[0007] Japanese Patent Application Nos. sho 58-163836 (September 16, 1983); hei 3-107438 (May 13, 1991), hei 3-136478 (June 7, 1991); hei 5-135656 (June 7, 1993); hei 6-296633 (November 30, 1994); hei 6-316435 (December 20, 1994); hei 7-65878 (March 24, 1995); hei 7-105780 (April 28, 1995); hei 7-244029 (September 22, 1995); hei 8-110712 (May 1, 1996); hei 10-27202 (February 9, 1998); hei 10-84137 (March 30, 1998); and hei 10-208635 (July 8, 1998) disclose heat-pipe equipped fusing roller apparatus.

[0008] Such fusing roller apparatus using heat-pipes can be instantaneously heated, thereby reducing power consumption. Fusing roller apparatus also have a short period of delay when switching between stand-by and a printing operation. In particular, the fusing roller apparatus disclosed in Japanese Patent Application Nos. hei 5-135656; hei 10-84137; hei 6-296633 and hei 10-208635 employ different types of heat sources at one end of the fusing rollers, that are positioned beyond the fixing areas. The arrangement of the heat source for each of these fusing roller apparatus increases the volume of the fusing roller apparatus and requires complex structures. Thus, there is a need to improve the structural complexity of such fusing roller apparatus.

[0009] The fusing roller apparatus disclosed in Japanese Patent Application Nos. sho 58-163836; hei 3-107438; hei 3-136478; hei 6-316435; hei 7-65878; hei 7-105780; and hei 7-244029 have their heat sources located within their fusing rollers, so that there remains a problem attributable to the increased volume of this apparatus described above.

A plurality of local heat pipes, however, are installed for each fusing roller, thereby complicating fabrication and manufacture of the fusing roller apparatus. The local arrangement of the heat pipes moreover, causes temperature deviations between heat-pipe contact portions and heat-pipe non-contact portions.

[0010] EP 0 399 376 discloses a heat fixing roller for a copying machine, wherein an insulating layer and a resistor layer are then formed on the surface of a hollow metal tube so that when a current is passed through the resistor layer, the outer surface of the fixing roller becomes heated.

[0011] JP 0 919 7863 discloses a sealed heat pipe which is heated by an external coil, wherein the sealed heat pipe contains a heat transfer liquid. This document forms the pre-characterising portion of the claims appended hereto.

[0012] It is an aim of the present invention to provide an electrophotographic image forming apparatus and process, that addresses these and other problems in the art.

[0013] A preferred aim is to provide a fusing roller apparatus for an electrophotographic image forming apparatus, in which local temperature deviation of a fusing roller is sharply reduced, thereby improving overall thermal distribution characteristics.

[0014] Another preferred aim of the present invention to provide a fusing roller apparatus for an electrophotographic image forming apparatus, which is easy to manufacture and is designed to minimize any increase in the size of the fusing roller apparatus.

[0015] Another preferred aim is to provide a fusing roller able to progress from its standby state to its printing state in a shorter period of time.

[0016] Another preferred aim is to provide a more energy efficient electrophotolithographic process and apparatus.

[0017] Another preferred aim is to provide a fusing roller, process for constructing a fusing roller and a process for fusing electrostatic images formed from toner onto a printable medium, with an assembly able to change the temperature of the fusing roller from room temperature to an operating temperature within a shorter period of time.

[0018] Another preferred aim is to provide a fusing roller, a process for constructing a fusing roller and a process for fusing electrostatic images formed from toner onto a printable medium, with an assembly that is able to allow the temperature of the fusing roller to remain at room temperature during a standby operational period.

[0019] Another preferred aim is to provide a fusing roller, process for constructing a fusing roller and a process for fusing electrostatic images formed from toner onto a printable medium, with an assembly that exhibits an improved thermal equilibrium and minimal local thermal differences on the cylindrical exterior surfaces of the fusing roller.

[0020] According to the first aspect of the present invention there is provided a fusing roller assembly, comprising: a cylindrical fusing roller providing an axially oriented hollow cavity; a heat pipe having opposite ends sealed, providing an evacuated chamber maintainable at a vacuum, coaxially positioned within said fusing roller; and an electrically conducting coil helically wound around an exterior cylindrical surface of said heat pipe, coaxially interposed between and contacting said exterior cylindrical surface of said heat pipe and an interior cylindrical surface of said hollow cavity.

[0021] Preferably, prior to introduction of said coil into said cavity, said coil has an outer diameter greater than the inner diameter of the fusing roller such that at least some turns of said coil contact an interior cylindrical wall of said hollow cavity with a force.

[0022] Preferably, said heat pipe is formed of copper. Preferably, the fusing roller is formed of aluminum.

[0023] Preferably, the fusing roller assembly comprises a working fluid contained within said chamber. Suitably, the working fluid is distilled water. Preferably, an amount of said working fluid contained within said chamber is in the range of 5-50% by volume of said chamber. Ideally, an amount of said working fluid contained within said chamber is in the range of 5-15% by volume of said chamber.

[0024] Preferably, neighboring turns of said coil are axially spaced apart; and a spacer of a thermally conducting material is interposed between said neighboring turns of said coil. Preferably, said spacer is in simultaneous thermal contact with substantially an entire axial length of said interior cylindrical surface of said hollow cavity and with substantially an entire axial length of said exterior cylindrical surface of said heat pipe. Suitably, said fusing roller, said spacer and said heat pipe are made of aluminum. Ideally, said fusing roller is made of a thermally conductive material exhibiting a first coefficient of hardness, said spacer is made of a thermally conductive material exhibiting a second and lesser coefficient of hardness, and said heat pipe is made of a thermally conductive material exhibiting a third and least degree of hardness.

[0025] According to a second aspect of the present invention there is provided a fusing roller assembly, comprising: a cylindrical fusing roller providing an axially hollow cavity; a heat pipe having axially opposite ends sealed, providing an evacuated hollow interior chamber maintainable at a vacuum; an electrically conducting coil helically wound around an axial length of an exterior cylindrical surface of said heat pipe; and said heat pipe and said coil being positioned coaxially inside said hollow axial interior with said coil interposed between an interior circumferential, surface of said fusing roller and said exterior cylindrical surface of said heat pipe.

[0026] According to a third aspect of the present invention there is provided a fusing roller assembly, comprising: a cylindrical fusing roller providing a hollow axial cavity; a heat pipe having axially opposite ends sealed, providing an evacuated chamber maintainable at a vacuum; an electrically conducting coil helically wound around an axial length of an exterior cylindrical surface of said heat pipe; a spacer helical wound around said exterior cylindrical surface of said heat pipe between successive windings of said coil, maintaining each of said successive windings spaced axially apart; and said heat pipe, said coil and said spacer being positioned coaxially inside said hollow axial interior with said coil and said spacer interposed between an interior circumferential surface of said fusing roller and said exterior cylindrical surface of said heat pipe.

[0027] According to a fourth aspect of the present invention there is provided a process of manufacturing a fusing roller assembly, comprised of: forming a cylindrical fusing roller with a central, axially oriented interior cavity; forming a heat pipe having an interior chamber; inserting said heat pipe into said fusing roller to place said heat pipe at rest coaxially inside said interior cavity with an electrically conducting heating coil wound in a helical spiral with a plurality of axially spaced turns around a central axial length of an exterior cylindrical surface of said heat pipe; evacuating said interior chamber; partially filling said interior chamber with a quantity of a working fluid; hermetically sealing said interior chamber; and providing electrical connectivity across said heating coil.

[0028] Preferably, the process further comprises forming said fusing roller with said interior cavity exhibiting an interior first diameter; winding said heating coil to exhibit an exterior second diameter greater than said first diameter before insertion of said heating coil into said interior cavity; reducing said second diameter during said insertion; and releasing said heating coil to assume said second diameter after said insertion.

[0029] Preferably, the process comprises axially spacing apart successive turns of said coil; and interposing a spacer of a thermally conducting material between said successive turns of said coil.

[0030] Preferably, the process comprises axially spacing apart successive turns of said coil; and interposing a spacer of a thermally conducting material between said successive turns of said coil, with said spacer being in simultaneous thermal contact with substantially an entire axial length of an interior cylindrical surface of said cavity and with substantially an entire axial length of said exterior cylindrical surface.

[0031] For a better understanding of the invention, and to show how embodiments of the same may be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawings in which:

Figure 1 is a perspective view of a general electrophotographic image forming apparatus;

Figure 2 is a sectional view of a conventional fusing roller apparatus of an electrophotographic image forming apparatus;

Figure 3 shows the structure of a fixing unit of an electrophotographic image forming apparatus incorporating a conventional fusing roller apparatus;

Figure 4 shows the structure of a fixing unit of an electrophotographic image forming apparatus that incorporates a different conventional fusing roller apparatus;

Figure 5 is a cross-sectional view of a fixing unit of an electrophotographic image forming apparatus that incorporates a first embodiment of a fusing roller apparatus constructed according to the principles of the present invention;

Figure 6 is a partial perspective view of the structure of the fusing roller apparatus illustrated by Figure 5 albeit without illustration of details of the heat pipe;

Figure 6A is a partial cut-away cross-sectional detailed view of a resistance heating coil shown in Figure 6;

Figure 6B, 6C and 6D illustrate a sequence of steps in the construction of a fusing roller apparatus according to the principles of the present invention;

Figure 7 is a cross-sectional view illustrating the inner structure of the fusing roller apparatus shown by Figures 5 and 6;

Figure 8 is a cross-sectional detail illustrating a mode of operation of the embodiment shown in Figure 7;

Figure 9 is a two-coordinate graph illustrating change in temperature as a function of time;

Figure 10 is a cross-sectional view of a second embodiment of a fusing roller apparatus constructed according to the principles of the present invention;

Figure 11 is a partial longitudinal sectional view showing a detail X describing the fusing roller apparatus illustrated by Figure 10;

Figure 12 is a cross-sectional detail illustrating a mode operation of the embodiment shown by Figure 10;

Figure 13 is a two-coordinate graph illustrating change in temperature as a function of time;

Figure 14 is a graph illustrating the phase change of a working fluid illustrated as a function of temperature rise and the heat pipe working period of the heat pipe;

Figure 15 shows the internal structure of the heat pipe and the heat transfer marked to indicate the liquid-vapor phase change;

Figure 16 is a graph showing the saturation pressure variations as a function of the saturation temperatures for Fluorinert (TM) Electronic Liquid FC-40 and distilled water used separately as a working fluid;

Figure 17 is a graph of the ultimate tensile strength variations as a function of the temperature variations for the heat pipe materials of aluminum, copper and 304 stainless steel;

Figures 18A and 18B are graphs illustrating the maximum allowable stress and the maximum stress variations upon the heat pipe wall with respect to temperature variations when FC-40 and distilled water are respectively used as a working fluid;

Figures 19A and 19B are graphs illustrating the maximum stress variations with respect to the heat pipe thickness (T) variations when FC-40 and distilled water are respectively used as a working fluid; and

Figures 20 and 21 are graphs illustrating the temperature variations in the middle of the fusing roller with respect to time for the first embodiment of the fusing roller apparatus described above.

[0032] Figure 1 shows a general electrophotographic image forming apparatus, with an electrophotographic image forming apparatus that includes a paper ejector 1, a keypad 2, a control board cover 3, an upper-cover opening button 4, paper indication windows 5, a multi-purpose paper feed tray 6, a paper cassette 7, an optional cassette 8, and an auxiliary paper support 9.

[0033] Figure 2 is a cross-sectional view of a conventional fusing roller apparatus of an electrophotographic image forming apparatus, which uses a halogen lamp as a heat source. Figure 3 is a sectional view of the fusing roller of Figure 2 with the halogen lamp as a heat source and a pressure roller, as used in the conventional electrophotographic image forming apparatus. Referring to Figure 2, the conventional fusing roller apparatus 10 includes a cylindrical fusing roller 11 and a heat-generator 12, such as a halogen lamp, inside the fusing roller 11. As the exterior surface of fusing roller 11 must generate heat, fusing roller 11 is heated from the inside out by radiant heat from heat-generator 12.

[0034] Referring to Figure 3, a pressure roller 13 is located below the fusing roller 11 having a coated layer 11a formed of Teflon. The pressure roller 13 is elastically supported by a spring assembly 13a to press the print paper 14 passing between the fusing roller 11 and the pressure roller 13 against the fusing roller 11 by a predetermined force. As the print paper 14 carries a toner image 14a in a powder form between the fusing roller 11 and the pressure roller 13, the print paper 14 is hot pressed by the predetermined force. In other words, the toner image 14a is fused and fixed to the print paper 14 by the heat and force from the fusing roller 11 and the pressure roller 13.

[0035] A thermistor 15 is used for detecting and converting the surface temperature of the fusing roller 11 into an electric signal and a thermostat 16 for cutting off the power supply to the heat-generator 12, such as a halogen lamp, are installed adjacent to the fusing roller 11. When the surface temperature of the fusing roller 11 goes beyond a given threshold value, thermostat 16 interrupts electrical power to heat generator 12. The thermistor 15 detects the surface temperature of the fusing roller 11 and transmits the result of the detection to a controller (not shown) for the printer. The controller controls the power supply to the halogen lamp of heat-generator 12 according to the detected surface temperature of the fusing roller 11 to keep the surface temperature within a given range. The thermostat 16 serves as a thermal protector for the fusing roller 11 and neighboring elements, which operates when the thermistor 15 and the controller fail to control the temperature of the fusing roller 11.

[0036] A conventional fusing roller apparatus which employs the halogen lamp as a heat source unnecessarily consumes a large amount of power, and needs a considerably long warm-up period when the image forming apparatus is turned on for image formation. In other words, after the application of power, a standby period is followed until the temperature of the fusing roller 11 reaches a target temperature, for example, for a few tens of seconds to a few minutes. For the conventional fusing roller apparatus, because the fusing roller is heated by radiant heat from the heat source, the heat transfer rate is low. In particular, compensation for temperature variations due to a drop in the temperature of the heat roller caused by contact with a print paper is delayed, so that it is difficult to uniformly control the distribution of temperature of the fusing roller 11. Even in a stand-by mode where the operation of the printer is suspended, power must be periodically applied so as to keep the temperature of the fusing roller constant, thereby causing unnecessary power consumption. Also, it takes a considerable amount of time to switch the stand-by mode to an operating mode for image output, so that the resultant image cannot be rapidly output.

[0037] Figure 4 is a sectional view of a conventional fusing roller apparatus applied to an electrophotographic image forming apparatus. Heating plate 22 is placed in a lower portion of a flexible cylindrical film tube 21, and a pressure roller 23 is mounted underneath the heating plate 22. The film tube 21 is rotated by a separate rotation unit and is locally heated and deformed at a part between the heating plate 22 and the pressure roller 23. This method of locally heating the film tube 21 by the heating plate 22 is advantageous in terms of low power consumption. The local heating method is unsuitable, however, for high-speed printing.

[0038] A fixing unit of an electrophotographic image forming apparatus incorporating a first embodiment of a fusing roller apparatus according to the present invention is shown in Figure 5, while Figure 6 is a perspective view of Figure 5 showing the structure of the fusing roller apparatus in greater detail, and Figure 7 is a longitudinal sectional view of the fusing roller apparatus of Figures 5 and 6.

[0039] Referring to Figures 5, 6 and 6A together, the fixing unit 200 includes a fusing roller apparatus 210 which rotates in a direction in which a print paper 250 bearing a toner image 251 is ejected, i.e., clockwise as viewed in Figure 5, and a pressure roller 220 which rotates counterclockwise in contact with the fusing roller apparatus 210. The fusing roller apparatus 210 includes a cylindrical fusing roller 212 having a protective outer cylindrical layer 211, which is formed on the surface thereof by coating with Teflon, and a heat-generator 260 installed in the fusing roller 212. A thermistor 230 for sensing the surface temperature of the fusing roller 212 is mounted on the top of the fusing roller 212.

[0040] The heat-generator 260 is installed within the fusing roller 212 to generate heat using power supplied from an external power supply unit (not shown). Heating generator 260 has an internal heat pipe 262 which is installed within the multiple turns of heating unit 213 with both ends 264 of heat pipe 262 hermetically sealed to maintain a predetermined pressure. The internal heat pipe 262 accommodates a working fluid 214 at a predetermined volume quantity.

[0041] The thermistor 230 for sensing the surface temperature of the fusing roller 212 and protective layer 211 is installed above the fusing roller 212 in contact with the protective layer 211. A thermostat 240 for cutting off the power of a power supply unit when the surface temperature of the fusing roller 212 and protective layer 211 rapidly increases is also installed above the fusing roller 212.

[0042] The heating unit 213 is supplied with power from the external power supply unit to generate heat. The heating unit 213 is constructed as a spiral resistive heating coil contacting the inside of the fusing roller and the outside of the internal heat pipe 262.

[0043] Thermistor 230 is in direct physical contact with protective layer 211 and senses the temperature of the protective layer 211. The inner space formed by the interior cylindrical cavity 242 of the fusing roller 212 is occupied by heat-generator 260. Heating unit 213 may be a helical winding of multiple turns made with a spiral resistance heating coil installed along inner cavity 242 in direct physical contact with the inner cylindrical wall of fusing roller 212. The heating unit 213 includes a heat-generating wire 213a formed of an electrically resistive material such as either iron chromium (Fe-Cr) or nickel-chromium (Ni-Cr) coil, and an electrically insulating covering layer 213c formed of an electrical dielectric material such as magnesium oxide (MgO) protects the heat-generating wire 213a. Insulating covering layer 213b of the heating unit 213 prevents deformation or characteristic changes in heat-generating wire 213a, which are prone to occur over time or are caused by temperature variations in a working fluid 214 to be described later. An outer layer 213b made of a relatively inert material such as stainless steel, forms a protective sheath around insulating layer 213c. Both ends of the heater 213a are not covered with the covering layer 213b to form electrical contacts 215 at both ends of the fusing roller 212. Each end of the covering layer 213b is finished by a seal 213d in order to prevent the dielectric layer 213c formed of MgO being exposed to air. Preferably, the seal 213d is formed of zirconia (ZrO_2) ceramic to improve heat-resistance, corrosion-resistance and endurance. Preferably, the resistance of the heating unit 213 is 25-40 Ω with respect to 220V AC power and 5-20 Ω with respect to 110V AC power.

[0044] As illustrated in Figures 6B, 6C and 6D, the distance between diametrically opposite interior walls of the inner cylindrical surface 246 of fusing roller 212 is d_1, while the outer cylindrical surface of the multiple turns of heating unit 213 has a diameter of d_2. As shown by Figure 6B, heating unit 213 is spirally wound in multiple turns of a helix, around substantially the entire axial length of the exterior cylindrical surface of heat. pipe 262. The average outer cylindrical diameter of the several turns of heating unit 213 is d_2, which is slightly greater than d_1. As shown in Figure 6C, opposite axially directed forces F are applied to electrodes 215 at axially opposite ends of coil 213 to reduce the diameter of coil 213 to a value, that is less than d_1, while heat pipe 262 together with heating unit 213 are inserted coaxially into the interior cavity 242 of fusing roller 212. As shown Figure 6D, upon removal of force F, the outer surfaces of each loop of coil 213 are in direct physical and thermal contact with interior circumferential surface 246 of fusing roller 212; in essence, the removal of force F allows coil 213 to assume an outer cylindrical diameter d_1, equal to the inner diameter of fusing roller 212. The pitches x_1, x_2 between neighboring loops of coil 213 are not necessary equal. What is important however, is that most, or all of the exterior surface of each loop of coil 213 lie in direct physical and thermal contact with interior cylindrical surface 246 of fusing roller 212.

[0045] Then, as shown by the transition between Figure 6C and Figure 6D, once heat generator 260 is installed within the internal cavity 242 of fusing roller 212, air pressure is applied to the interior of heat pipe 262 in order to expand the cylindrical wall of heat pipe 262 radially outwardly until the inner surfaces of heating unit 213 are substantially in direct physical contact with the cylindrical outer surface of heat pipe 262 and simultaneously in direct physical and thermal contact with the interior cylindrical surface 246 of the fusing roller. The interior cavity of heat pipe 262 is then filled with a predetermined quantity of working fluid 214 and heat pipe 262 is hermetically sealed at a predetermined pressure.

[0046] The working fluid 214 is contained in the sealed inner space of heat pipe 262 in around the cylindrical exterior of which heat-generator is installed. The working fluid 214 is contained in an amount of 5-50% by volume, and preferably, 5-15% by volume based on the inner volume 268 of heat pipe 262. The working fluid 214 prevents local surface temperature deviations of the rotating fusing roller 212, which could otherwise occur due to the presence of the heating unit 213, based on the principles of a heat pipe, and serves as a thermal medium capable of uniformly heating the entire cylindrical volume of heating pipe 262 and simultaneously, of fusing roller 212 within a shorter period of time than is currently available with conventional apparatus. If the amount of the working fluid 214 is less than about 5% by volume based on the volume of the fusing roller 212, a dry-out phenomenon is likely to occur in which the working fluid is not fully vaporized and liquified immediately after vaporization should have otherwise occurred.

[0047] Heat pipe 262 may be formed of a stainless steel (such as Allegheny Ludlum Stainless Steel Chromium-Nickel 304SS) or copper (Cu). If heat pipe 262 is formed of stainless steel, most of the well-known working fluids, except for water (distilled water) can be used. Fluorinert (TM) Electronic Liquid FC-40 (available from 3M Corporation) is the most preferred alternative to water as working fluid 214 and will herein be referred to as FC-40. Meanwhile, if the heat pipe 262 is formed of copper, almost all of the well-known working fluids can be used. Water (e.g., distilled water) is the most preferred working fluid for heat pipe 262 made of copper.

[0048] Referring to Figure 7, end caps 264 are coupled to both of the axially opposite ends of heat pipe 262 to seal the interior cylindrical cavity of heat pipe 262 and thereby form a vacuum tight sealed inner space 268. The axially opposite terminal ends of coil 213 form electrodes 215 that extend axially beyond heat pipe 262 to operationally engage electrical contacts such as slip rings (not shown) that in turn, provide an electrical current through coil 213. Non-conductive brushings and gear-binding caps may also be mounted on the exterior cylindrical surface of fusing rollers. The electrodes 215 are electrically connected to electrically conducting end leads of heat coil 213 of heat-generator 260. Although the electrical connection that couples the structure of the heat-coil 213 and the electrodes 215 to a source of electrical power is not illustrated in great detail, this structure can be easily implemented.

[0049] During operational use, fusing roller apparatus 210 having the structure described above is rotated by a separate rotation unit. For this purpose, additional parts may be installed. For example, a gear-binding cap is an additional part to be coupled to a rotating spur gear required for rotating fusing roller apparatus 210.

[0050] In a fixing unit 200 of the electrophotographic image forming apparatus constructed according to the principles of the present invention, as an electrical current flows into the heat-coil 213 through electrodes 215, *i.e.*, from an electrical power supply, heat-coil 213 generates heat due to resistance heating as the electrical current flows through helical coil 213 of heat generator 260, and fusing roller 212 is heated from the inside out by the resulting heat. At the same time, working fluid 214 contained in heat pipe 262 is vaporized by the heat. The heat generated by helical coil 213 is transferred to the cylindrical wall of the fusing roller 212, and at the same time the body of the fusing roller 212 is uniformly heated by the vaporized working fluid. As a result, the surface temperature of the fusing roller 212 reaches a target fusing temperature within a substantially shorter period of time.

[0051] A wick 244 made of a perforated layer or screen of metal made from copper or stainless steel is formed in a cylindrical shape to serve as a capillary; wick 244 may be placed along interior circumferential surface 266 of heat pipe 262. Suitable materials for heat pipe 262 are listed in Table 2. FC-40 or water (distilled water), previously described, or the materials listed in Table 3 may be used as working fluid 214. When water (distilled water) is selected as working fluid 214, the fusing roller apparatus can be implemented at low cost without environmental concern. Once the temperature of the fusing roller 212 reaches a target fusing temperature at which the toner image is fused, the toner image is transferred (i.e., permanently bonded) to the printable paper. As the printable paper to which the toner image has been transferred absorbs the heat from the fusing roller 212, the vaporized working fluid changes back into its liquid phase inside the cavity 268 of heat pipe 262. The liquefied working fluid may be subsequently heated again by heat-generator 260 to vaporize, so that the temperature of the fusing roller 212 can be maintained at a predetermined temperature.

[0052] If the fusing temperature of toner is in the range of 160-180°C, a fusing roller apparatus constructed according to the present invention can reach the target temperature within approximately ten seconds. Then, the surface temperature of the fusing roller 212 is maintained by intermitted application of an electrical current to heating unit 213, within a predetermined range of temperature by the thermistor 230 in response to the surface temperature of the fusing roller 212 sensed by thermistor 230. If the thermistor 230 and a controller fail to properly control the surface temperature so that the surface temperature of fusing roller 212 suddenly rises, a thermostat 240 located in close operational proximity to the cylindrical surface of fusing roller 212 senses the surface temperature of the fusing roller 212 and cuts off the supply of electrical current to coil 213 to prevent overheating. The power supply operation may be varied depending on the target temperature. It will be appreciated that the power supply operation can be controlled by such control techniques as periodic power on/off control or a duty cycle ratio.

[0053] A fusing roller apparatus having the configuration described in the forgoing paragraphs may be manufactured by the steps of:

(a) preparing a metal pipe as a material for the fusing roller;

(b) preparing a metal tube as the structure for a heat pipe;

(c) cleaning the exposed surfaces of the metal pipe and the metal tube by washing the metallic pipe and the metal tube with distilled water or volatile liquid;

(d) cleaning the exposed surfaces of a spiral resistance heating coil by washing the spiral resistance heating coil with distilled water or volatile liquid;

(e) winding the spiral resistance heating coil as a helical coil with an outer diameter that is equal to or slightly larger than the inner diameter of the metal pipe, into the annular outer cylindrical volume of the heat pipe;

(f) optionally, inserting a wick formed as a cylinder, to line the interior cylindrical surface of the heat pipe;

(g) sealing opposite base ends of the heat pipe with end caps such that a working fluid inlet remains, while both end leads of the resistance heating coil helically wound around the heat pipe serve as electrical leads;

(h) inserting the heat pipe bearing the helically wound heating coil, coaxially into the interior of the metal pipe;

(i) inflating the sealed heat pipe with a high pressure inert gas, to radially expand the cylindrical shell of the heat pipe until either the windings of the heating coil make direct physical and thermal contact simultaneously with both the inner cylindrical surface of the fusing roller and the outer cylindrical surface of the heat pipe or alternatively, the radial air gap separation between the outer cylindrical surface of the heat pipe and the inner cylindrical surface of the fusing roller, is minimized;

(j) purging extraneous gases from the inner volume of the heat pipe by evacuating, heating, and cooling the heat pipe to exhaust gases from the inner volume of the pipe to create a vacuum within the inner volume;

(k) injecting 5-50% by volume, a working fluid (such as either FC-40 or distilled water) through a working fluid inlet into the interior cavity of the heat pipe;

(l) sealing the working fluid inlet of the heat pipe;

(m) spray-coating the surface of the metal pipe with Teflon, and drying and polishing the metallic pipe to form a protective coating on the fusing roller;

(n) inserting a non-conductive brushing as a bearing into one end of the fusing roller; and

(o) mounting a gear-mounting cap made of metal, heat-resistant plastic, or epoxy at the one end of the fusing roller assembly.

[0054] During the manufacture of the fusing roller apparatus, when weld-capping the metallic pipe with end caps 264 at axially opposite base ends after the insertion of a wick 214, if a wick is to be used, argon gas is injected into interior cavity 268 of the metal tube via the working fluid inlet for the purpose of preventing oxidation of the heat pipe. Before injecting the working fluid into the heat pipe, extraneous gases are purged from the inner volume 268 and the inner volume is evacuated and is repeatedly heated and cooled under a vacuum so as to exhaust all gases out of the inner volume of the heat pipe, thereby removing substantially all foreign substances adhering to the inner wall of the heat pipe. For example, in one process for purging interior cavity 268, the heat pipe is heated to a temperature of 250°C with an internal pressure of forty (40) atmospheres. At room temperature, interior cavity 268 should have a perfect pressure; that is, there should be no molecules within cavity 268.

[0055] Figures 8 and 9 illustrate the thermal mode of operation of the embodiment shown in Figure 7. The individual turns of heating unit 213 either directly heat fusing roller 212 or heat pipe 262 by thermal conduction, as indicated by arrows K and indirectly heat the air space represented by gap A between neighboring turns of heating unit 213, as indicated by Arrows L. Depending upon the radial placement of individual turns of heating unit 213, those turns also indirectly heat either working fluid 214 or fusing roller 212, by radiant heating, as indicated by arrows M. Temperature T_1, T_3 taken in radial alignment with two neighboring turns of heating unit 213 provides substantially identical rise time and temperature profile, as shown by Figure 9 over both the transient time t_1 and the transient time t_2. Temperature T_2, measured within gap A between those two neighboring turns of heating unit 213, initially follows temperature T_1, T_3, but subsequently lags those temperatures with lower temperature measurement, over the transient temperature rise time t_1. Subsequently, during the quiescent period t_2, all three temperatures are substantially identical.

[0056] . Referring to Figures 10 through 13, an intermediate portion, or spacer 213' may be inserted between heat pipe 262 and fusing roller 212 for transmitting heat from the heating unit 213 and the heat pipe 262 to the fusing roller 212, in a gap A between adjacent spirals of a resistive heating unit 213. Preferably, the height t_1* of spacer 213' is equal to the height t_2* of the heating unit 213 or greater to form a space E as large as the difference between the height t_1 of 213' and the height t_2 of the heating unit 213. The space E contains air, so that heat generated by the heating unit 213 is transmitted to the fusing roller 212 as radiant heat via the air.

[0057] By using spacer 213' filling the gap A and transmitting heat from a heating coil and heat pipe 262 to fusing roller 212, heat conductivity can be considerably enhanced with the design shown by Figures 10, 11 and 12 compared to a design that uses only a heating coil for heat transmission, and the temperature of the entire fusing roller 212 is uniformly increased to a target temperature. Accordingly, it is preferable to use a material having excellent heat conductivity, particularly, with a group 10 material such as aluminum (Al), used to construct spacer 213'.

[0058] Heat pipe 262 has a right cylindrical pipe shape and is hermetically sealed at both of its ends. A predetermined amount of the working fluid 214 is contained in the internal cavity 268 of heat pipe 262. Preferably, a netlike wick structure 244 is provided on the inside of heat pipe 262 so that heat from the heating unit 213 can be uniformly transmitted throughout the interior of heat pipe 262 within a short time. It is apparent that various modifications can be made for uniform heat transmission throughout heat pipe 262.

[0059] The working fluid 214 is evaporated due to heat generated and transmitted from the heating unit 213 and transmits the heat to the fusing roller 212, thereby functioning as a thermal medium which prevents significant difference in the surface temperature over the axial length of the fusing roller 212, and heats the entire fusing roller 212 within a very short time. For this function, the working fluid 214 has a volume rate of 5-50%, preferably, 5-15%, with respect to the volume of the internal cavity 268. When the volume rate of the working fluid 214 is no greater than about 5%, a probability of dry-out phenomenon is very high. Accordingly, it is preferable to avoid a design that uses working fluid 214 having a volume that is no greater than 5% of the volumetric capacity of cavity 268.

[0060] The working fluid 214 is selected according to the material of the heat pipe 262. In other words, when the heat pipe 262 is formed of stainless steel, it is not preferable to use water, that is, distilled water, as the working fluid 214. Except for distilled water, most working fluids known up to now can be used. It is most preferable to use FC-40 manufactured by the 3M Corporation.

[0061] Figures 12 and 13 illustrate the thermal mode of operation of the embodiment shown by Figure 10. As indicated by arrows K, neighboring windings of heating unit 213, depending upon their radial disposition, may heat either fusing roller 212 or heat pipe 262 and working fluid 214 by direct thermal conduction. The neighboring turns may, due to their immediate proximity to intervening spacer 213', also directly heat spacer 213', as indicated by arrows L. Spacer 213' also directly heats fusing roller 212 by thermal conduction. These turns of heating unit 213 also, and again depend upon their radial disposition, indirectly heat fusing roller 212 and working fluid 214, as indicated by arrows M. Measurements of temperatures T_4, T_5 at the surfaces of the Teflon coating 211 on fusing roller 212, in radial alignment respectively with one turn of heating unit 213 and the spacer 213' between two neighboring turns of heating unit 213, are identical both during a transient and quiescent period of time, as shown by Figure 13. Consequently, the spacers provide almost identical, but certainly uniformity in external temperature of the fusing roller along its entire axial length. It should be noted that the diameter of each turn of heating unit 213 should be approximately equal, but will most likely be somewhat less in value than the radial cross-sectional dimension of the intermediate spacer 213'.

[0062] Spacer 213' may be made of type 10 aluminum while the fusing roller 212 is made of type 60 aluminum. Type 10 aluminum is more easily deformed however, and the spacer 213' is therefore more flexible. If heat pipe 262 is made of either copper or aluminum, when inflated by high pressure of air, the cylindrical shell of heat pipe 262 will be distorted and spacer 213' deformed to the point that both the radially inner and radially outer surface of the series 10 aluminum spacer 213' make direct physical and thermal contact simultaneously with both the outer diameter of heat pipe 262 and the interior diameter of type 60 aluminum fusing roller 212; the type 60 aluminum fusing roller however, will be not deformed. The hardness of type 50 aluminum is greater than type 60 series aluminum, and the hardness of both type 50 and type 60 series aluminum is greater than the hardness of type 10 aluminum. The heat transfer characteristics of type 50, type 60 and type 10 series aluminum are substantially equal and the electrical conductivity of type 50, type 60 and type 10 series aluminum are substantially identical.

[0063] A fusing roller apparatus having the configuration for the second embodiment described in the foregoing paragraphs may be manufactured by the steps of:

(a) preparing a metal pipe as a material for the fusing roller;

(b) preparing a metal tube as the structure for a heat pipe;

(c) cleaning the exposed surfaces of the metal pipe and the metal tube by washing the metallic pipe and the metal tube with distilled water or volatile liquid;

(d) cleaning the exposed surfaces of a spiral resistance heating coil by washing the spiral resistance heating coil with distilled water or volatile liquid;

(e) optionally, inserting a wick formed as a cylinder, to line the interior cylindrical surface of the heat pipe;

(f) winding the spiral resistance heating coil as a helical coil with an outer diameter that is equal to or slightly larger than the inner diameter of the metal pipe, into the annular outer cylindrical volume of the heat pipe with a continuous spacer of a thermally conducting material (such as type 10 aluminum) separating individual turns of the spiral heating coil, interposed between the outer cylindrical surface of the heat pipe and the inner cylindrical surface of the fusing roller;

(g) sealing opposite base ends of the heat pipe with end caps such that a working fluid inlet remains, while both end leads of the resistance heating coil helically wound around the heat pipe serve as electrical leads;

(h) inserting the heat pipe bearing the helically wound heating coil, coaxially into the interior of the metal pipe;

(i) inflating the sealed heat pipe with a high pressure inert gas, to radially expand the cylindrical shell of the heat pipe until the windings of spacer make direct physical and thermal contact simultaneously with both the inner cylindrical surface of the fusing roller and the outer cylindrical surface of the heat pipe;

(j) purging extraneous gases from the inner volume of the heat pipe by evacuating, heating, and cooling the heat pipe to exhaust gases from the inner volume of the pipe to create a vacuum within the inner volume;

(k) injecting 5-50% by volume, a working fluid (such as either FC-40 or distilled water) through a working fluid inlet into the interior cavity of the heat pipe;

(l) sealing the working fluid inlet of the heat pipe;

(m) spray-coating the surface of the metal pipe with Teflon, and drying and polishing the metallic pipe to form a protective coating on the fusing roller;

(n) inserting a non-conducive brushing as a bearing into one end of the fusing roller; and

(o) mounting a gear-mounting cap made of metal, heat-resistant plastic, or epoxy at the one end of the fusing roller assembly.

[0064] For easy understanding of the fusing roller apparatus operating in accordance with the present invention, the heat pipe associated with the present invention will be described. The term heat pipe refers to a heat transfer device that transfers heat from a high-heat density state to a low-heat density state using the latent heat required for the phase change of the working fluid from its liquid phase to its gaseous phase. Since the heat pipe utilizes the phase changing property of the working fluid, its coefficient of thermal conductivity is higher than that of any known metal. The coefficient of thermal conductivity of a heat pipe operating at room temperature is a few hundreds times greater than that of either silver or copper having a coefficient of thermal conductivity, k, of 400 W/mk.

[0065] Figure 14 is a graph illustrating the phase change of a working fluid as a function of temperature rise and the heat pipe working period. Table 1 shows the effective thermal conductivity of the heat pipe and other heat transfer materials.

Table 1

Material	Effective Thermal Conductivity (W/mK)
Heat pipe	50,000-200,000
Aluminum	180
Copper	400
Diamond	2,000

[0066] 4.18KJ of energy are required to raise the temperature of 1 kg of water from 25°C to 26°C. When the phase of the water changes from liquid to vapor without a temperature change, 2,442 kJ of energy is required. The heat pipe transfers about 584 times greater latent heat through the liquid-vapor phase change. For a heat pipe working at room temperature, the coefficient of thermal conductivity is a few hundreds times greater than that of either silver or copper that are known as excellent thermal conductors. The thermal conductivity of a heat pipe using a liquid metal as a working fluid working at high temperature amounts to 10^8 W/mK.

[0067] Figure 15 shows the internal structure of a heat pipe incorporating a wick to provide a capillary structure within the interior of the heat pipe, and its heat transfer process according to the liquid-to-vapor and the vapor-to-liquid phase changes. The resistance heating coil (not separately shown in Figure 15) and the wick are arranged in a cylindrical shape and are respectively mounted directly against the exterior cylindrical surface and directly against the interior circumferential surface of the heat tube. Table 2 shows the recommended and NOT-recommended heat pipe materials for a variety of working fluids.

Table 2

Working fluid	Recommended	NOT recommended
Ammonia	Aluminum, Carbon steel, Stainless steel, Nickel	Copper
Acetone	Aluminum, Copper, Stainless steel, Silica	-
Methanol	Copper, Stainless steel, Nickel, Silica	Aluminum
Water	Copper, 347 Stainless steel	Aluminum, Stainless steel, Nickel, Carbon steel, Inconel, Silica
Thermex	Copper, Silica, Stainless steel	-

[0068] Table 3 shows a variety of suitable working fluids for different working temperature ranges.

Table 3

Extreme low temperature (-273 ~ -120°C)	Low temperature (-120 ~ -470°C)	High temperature (-450 ~ -2700°C)
Helium	Water	Cesium
Argon	Ethanol	Sodium
Nitrogen	Methanol, Acetone, Ammonia, Freon	Lithium

[0069] We have found that there are several considerations in selecting a working fluid: 1) compatibility with the material of the heat pipe used; 2) a working fluid that is appropriate working temperature within the heat pipe; and 3) thermal conductivity of the working fluid.

[0070] When a heat pipe type fusing roller is formed of stainless steel (SUS) or copper (Cu), suitable working fluids are limited in terms of the compatibility with the material of heat pipe and the working temperature. FC-40 has a one atmosphere or less saturation pressure at a working temperature of 165°C and is considered to be a relatively suitable material.

[0071] FC-40 is known to be non-toxic, non-flammable and compatible with most metals. FC-40 also has a zero-ozone depletion potential. According to the thermodynamics of FC-40 as a working fluid, the relation between the saturation temperature and pressure is expressed by formula (1) :

$$\log_{10} P(torr) = A - \frac{B}{(T + 273)} \quad (1)$$

where A= 8.2594, and B = 2310, and temperature T is measured in degrees Celsius.

[0072] Figure 16 is a graph showing the saturation pressure variations with respect to saturation temperature for FC-40 and water as a working fluid. Table 4 shows the saturation pressures of FC-40 at particular saturation temperatures taken from Figure 14.

Table 4

Saturation Temperature (°C)	Saturation Pressure (bar)
100	0.15
150	0.84
200	3.2
250	9.3
300	22.54
350	47.5
400	89.5
450	154.6

[0073] In terms of safe operation of the heat pipe, suitable materials for the heat pipe and the thickness of its end cap are determined according to the American Society of Mechanical Engineers (i.e., ASME) code which is a safety measuring standard for pressure containers. For example, if the thickness of a cylindrical heat pipe is within 10% of its diameter, maximum stresses applied to the wall ($\sigma_{max(1)}$) and semispherical end cap ($\sigma_{max(2)}$) of the heat pipe are expressed as:

$$\sigma_{max(1)} = \frac{\Delta P d_0}{2t_1} \quad (2)$$

$$\sigma_{max(2)} = \frac{\Delta P d_0}{2t_2}$$

where ΔP is difference in pressure between inside and outside the heat pipe, d_0 is the outer diameter of the heat pipe, t_1 is the thickness of the heat pipe, and t_2 is the thickness of the end cap.

[0074] According to the ASME code, the maximum allowable stress at an arbitrary temperature is equal to 0.25 times the maximum ultimate tensile strength at that temperature. If the vapor pressure of a working fluid in the range of the heat pipe is working temperature is equal to the saturation vapor pressure of the working fluid, the difference in pressure (ΔP) is equal to the difference between the vapor pressure and atmospheric pressure.

[0075] Figure 17 is a graph of the ultimate tensile strength variations for a variety of heat pipe materials as a function of temperature variations for three different constructions of fusing rollers made with heat pipes of aluminum (Al), copper (Cu) and 304 stainless steel (SS304), taken over a temperature range extending between approximately 0°C and approximately 500°C. Figure 18A is a graph showing the maximum allowable stress and variations of maximum stress acting upon the heat pipe wall with respect to temperature variations when FC-40 is used as a working fluid for heat pipes constructed of aluminum, copper and 304 stainless steel. Figure 18B is a graph of variations of maximum stress acting upon copper heat pipe wall with respect to temperature variations when distilled water is used as a working fluid over a temperature range extending between approximately 0°C and approximately 300°C, for heat pipes constructed of aluminum, copper and 304 stainless steel. As shown in Figure 18A, the maximum allowable stress of the stainless steel (SS304) is much greater than that of either copper or aluminum. Safe operation without working leakage of the fluid is ensured for a heat pipe and end caps constructed of stainless steel (SS304) up to a working temperature of about 400°C.

[0076] Figures 19A and 19B are graphs that illustrate variations in the maximum stress acting upon a heat pipe copper with respect to pipe thickness variations when FC-10 and distilled water are used as a working fluid, respectively over a temperature range that extends from more than 150°C to less than 500°C. As shown in Figures 19A and 19B, although the thickness of the heat pipe varies from 0.8 mm up to 1.5 mm for FC-10 used as a working fluid, and from

1.0 mm up to 1.8mm for distilled water used as a working fluid, respectively, the maximum stress acting upon the heat pipe does not change very much at an operating temperature greater than approximately 165°C , but less than 200°C.

[0077] Figures 20 and 21 are graphs of the temperature variations (over a range between 0°C and 400°C) measured in the middle of the fusing roller with respect to time (over a period between zero and sixty-five seconds) for the first embodiment of the fusing roller apparatus described above. The fusing roller apparatus had a fusing roller made of copper and contains distilled water as a working fluid. The fusing roller had a thickness of 1.0 mm, an outer diameter of 17.85 mm, and a length of 258 mm. This test was performed at a fusing roller rotation rate of 47 rpm with a spiral resistance heating coil resistance of 32 Ω, a voltage of 200 V, and an instantaneous maximum power consumption of about 1.5 kW. The spiral resistance heating coil was in direct contact with the inner cylindrical surface of the fusing roller.

[0078] Figure 20 shows measurements for a fusing roller apparatus containing distilled water as a working fluid that occupies 10% of the inner volume of the fusing roller. Figure 21 shows measurements for a fusing roller apparatus containing distilled water occupying 30% of the volume of the fusing roller. Referring to Figure 20, this prototype takes about 8 to 12 seconds to raise the temperature of the fusing roller from room temperature of about 22°C to an operating temperature of about 175°C and less than 14 seconds to reach 200°C. Referring to Figure 21, it takes about 13 seconds to raise the temperature of the fusing roller from room temperature of about 22°C to 175°C and only about 22 seconds to 200°C.

[0079] Comparing the results of Figures 20 and 21, it is apparent that the rate of temperature increase varies depending on the volume ratio of working fluid contained in the sealed interior of the fusing roller. According to the results of experiments performed under various conditions, the fusing roller is operable with an amount of working fluid occupying 5-50% of the inner space of the fusing roller. The rate of temperature increase is high with only 5-15% of the volume of the fusing roller filled with working fluid.

[0080] Compared with a conventional image forming apparatus in terms of rate of temperature increase, for an image forming apparatus adopting one of the several possible designs for a fusing roller apparatus according to the present invention, there is no need to continuously supply power to the fusing roller apparatus during the stand-by state. Although the power is supplied when formation of an image starts, a fusing roller apparatus constructed according to the present invention can form an image, i.e., can still fuse a toner image, at a high speed, faster than contemporary equipment.

[0081] When the volume of the working fluid is more than 50% by volume, the rate of temperature increase becomes impractically slow. Meanwhile, if the volume of the working fluid is less than 5% by volume, a dry-out phenomenon either occurs or becomes likely to occur due to the insufficient supply of the working fluid, so that the fusing roller either does not function as well or does not function at all as a heat pipe.

[0082] In a fusing roller apparatus constructed according to the principles of the principles of the present invention, electrical power can be applied at a voltage of 90-240 volts and a frequency of 50-70 Hz, as well as at higher frequencies.

[0083] As described above, the fusing roller apparatus constructed according to the present invention includes a heating coil and a working fluid in the body of the metallic fusing roller having excellent conductivity, so that the surface of the fusing roller can be instantaneously heated up to a target fusing temperature to fix toner images that have been transferred to a print paper. Compared with a conventional halogen lamp type or direct surface heating type fusing roller apparatus using a palladium (Pd), ruthenium (Ru) or carbon (C) based heater, the fusing roller of the present invention can reach a target fusing temperature within a shorter period of time with reduced power consumption and the surface temperature of the fusing roller can be uniformly maintained. The fusing roller apparatus of the present invention needs neither a warm-up and stand-by period, and thus any image forming apparatus, such as a printer, copy machine, or facsimile, equipped with the fusing roller apparatus of the present invention, does not need to supply power to the fusing roller to ready for printing. Thus, overall power consumption of the image forming apparatus is reduced. In addition, the fusing roller apparatus of the present invention is based on the principle of a heat pipe, so that the temperature distribution in the longitudinal direction of the fusing roller can be uniformly controlled, thereby optimally improving toner fusing characteristics.

[0084] In addition, the fusing roller apparatus of the present invention can be easily manufactured on a mass scale, and ensure safe operation. The parts of the fusing roller apparatus are compatible with other commercially available parts. The quality of the fusing roller apparatus can be easily controlled. A high-speed printer can be implemented with the fusing roller apparatus according to the present invention.

[0085] The fusing roller apparatus and the method for manufacturing the fusing roller apparatus according to the present invention provide the following advantages.

[0086] First, the fusing roller apparatus can be manufactured by simple automated processes.

[0087] Second, the temperature variations in the axial, or longitudinal direction of the heat pipe are small (within the range of ±1°).

[0088] Third, a high-speed printer can be easily implemented with the fusing roller apparatus.

[0089] Fourth, the heat source and the heat pipe, which are the main elements of the fusing roller apparatus, are formed as separate units, so that the fusing roller apparatus can be easily manufactured on mass scale and ensures safe operation. The parts of the fusing roller apparatus are compatible with other commercially available parts. The quality of the fusing roller apparatus can be easily controlled.

[0090] Fifth, due to continuous vaporization and condensation cycles of the working fluid contained in the sealed heat pipe, although the pressure inside the heat pipe increases at a high temperature (one atmosphere or less at 165°C for FC40), the risk of explosion or serious deformation is very low.

[0091] While this invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention as defined by the appended claims.

Claims

1. A fusing roller assembly, comprising:

   a cylindrical fusing roller (212) providing an axially oriented hollow cavity (242);

   a heat pipe (262) having opposite ends sealed, providing an evacuated chamber maintainable at a vacuum, coaxially positioned within said fusing roller; and

   characterised by:

   an electrically conducting heating coil (213) helically wound around an exterior cylindrical surface of said heat pipe, coaxially interposed between and contacting said exterior cylindrical surface of said heat pipe and an interior cylindrical surface of said hollow cavity.

2. The fusing roller assembly of claim 1, wherein prior to introduction of said coil (213) into said cavity (242), said coil has an outer diameter greater than the inner diameter of the fusing roller such that at least some turns of said coil contact an interior cylindrical wall of said hollow cavity with a force.

3. The fusing roller assembly of claim 1 or 2, wherein said heat pipe (262) is formed of copper.

4. The fusing roller assembly of claim 1, 2 or 3, wherein the fusing roller (212) is formed of aluminum.

5. The fusing roller assembly of any preceding claim, comprising a working fluid (214) contained within said chamber.

6. The fusing roller assembly of claim 5, wherein the working fluid (214) is distilled water.

7. The fusing roller assembly of claim 5 or 6, wherein an amount of said working fluid (214) contained within said chamber is in the range of 5-50% by volume of said chamber.

8. The fusing roller assembly of claim 5 or 6, wherein an amount of said working fluid (214) contained within said chamber is in the range of 5-15% by volume of said chamber.

9. The fusing roller assembly of any preceding claim, wherein:

   neighboring turns of said coil (213) are axially spaced apart; and

   a spacer (213') of a thermally conducting material is interposed between said neighboring turns of said coil.

10. The fusing roller assembly of any preceding claim, wherein:

    neighboring turns of said coil (213) are axially spaced apart; and
    a spacer (213') of a thermally conducting material is interposed between said neighboring turns of said coil, with said spacer being in simultaneous thermal contact with substantially an entire axial length of said interior cylindrical surface of said hollow cavity and with substantially an entire axial length of said exterior cylindrical surface of said heat pipe.

11. The fusing roller assembly of claim 9 or 10, wherein said fusing roller (212), said spacer (213') and said heat pipe

(262) are made of aluminum.

12. The fusing roller assembly of claim 9, 10 or 11, wherein said fusing roller (212) is made of a thermally conductive material exhibiting a first coefficient of hardness, said spacer (213') is made of a thermally conductive material exhibiting a second and lesser coefficient of hardness, and said heat pipe (262) is made of a thermally conductive material exhibiting a third and least degree of hardness.

13. A process of manufacturing a fusing roller assembly, comprised of:

forming a cylindrical fusing roller (212) with a central, axially oriented interior cavity;

forming a heat pipe (262) having an interior chamber; and **characterised by**
inserting said heat pipe (262) into said fusing roller (213) to place said heat pipe at rest coaxially inside said interior cavity with 'an electrically conducting heating coil (213) wound in a helical spiral with a plurality of axially spaced turns around a central axial length of an exterior cylindrical surface of said heat pipe;
evacuating said interior chamber;
partially filling said interior chamber with a quantity of a working fluid (214);
hermetically sealing said interior chamber; and
providing electrical connectivity across said heating coil (213).

14. The process of claim 13, further comprising:

forming said fusing roller (212) with said interior cavity exhibiting an interior first diameter;

winding said heating coil (213) to exhibit an exterior second diameter greater than said first diameter before insertion of said heating coil into said interior cavity;

reducing said second diameter during said insertion; and

releasing said heating coil (213) to assume said second diameter after said insertion.

15. The process of claim 13 or 14, wherein said quantity of working fluid (214) contained within said heat pipe is in the range of 5-50% by volume of said interior chamber.

16. The process of claim 13 or 14, wherein said quantity of working fluid (214) contained within said heat pipe is in the range of 5-15% by volume of said interior chamber.

17. The process of any of claims 13 to 16, further comprising:

axially spacing apart successive turns of said coil (213); and

interposing a spacer (213') of a thermally conducting material between said successive turns of said coil.

18. The process of any of claims 13 to 16, further comprising:

axially spacing apart successive turns of said coil (213); and

interposing a spacer (213') of a thermally conducting material between said successive turns of said coil, with said spacer being in simultaneous thermal contact with substantially an entire axial length of an interior cylindrical surface of said cavity and with substantially an entire axial length of said exterior cylindrical surface.

19. The process of claim 17 or 18, wherein said fusing roller (212) and said spacer (213') are made of aluminum.

20. The process of claim 17, 18 or 19, wherein said fusing roller (212) is made of a thermally conductive material exhibiting a first coefficient of hardness, said spacer (213') is made of a thermally conductive material exhibiting a second and lesser coefficient of hardness, and said heat pipe (262) is made of a thermally conductive material exhibiting a third and least degree of hardness.

Patentansprüche

1. Aufschmelzrollenanordnung, die aufweist:

eine zylindrische Aufschmelzrolle (212), die einen axial orientierten Hohlraum (242) bereitstellt;
ein Wärmerohr (262), das gegenüberliegende Enden abgedichtet besitzt, eine evakuierte Kammer bildend, die unter einem Vakuum haltbar ist, koaxial positioniert innerhalb der Aufschmelzrolle und **gekennzeichnet durch**:

eine elektrisch leitende Heizspule (213), spiralförmig um eine zylindrische Außenfläche des Wärmerohrs herumgewickelt, koaxial zwischengefügt zwischen der zylindrischen Außenfläche des Wärmerohrs und einer inneren, zylindrischen Fläche des Hohlraums und dieses berührend.

2. Aufschmelzrollenanordnung nach Anspruch 1, wobei, vor der Einführung der Spule (213) in den Hohlraum (242), die Spule einen Außendurchmesser größer als der Innendurchmesser der Aufschmelzrolle besitzt, so dass mindestens einige Windungen der Spule eine innere, zylindrische Wand des Hohlraums mit einer Kraft berühren.

3. Aufschmelzrollenanordnung nach Anspruch 1 oder 2, wobei das Wärmerohr 262 aus Kupfer gebildet ist.

4. Aufschmelzrollenanordnung nach Anspruch 1, 2 oder 3, wobei die Aufschmelzrolle (212) aus Aluminium gebildet ist.

5. Aufschmelzrollenanordnung nach einem vorhergehenden Anspruch, die ein Arbeitsfluid (214), enthalten innerhalb der Kammer, aufweist.

6. Aufschmelzrollenanordnung nach Anspruch 5, wobei das Arbeitsfluid (214) destilliertes Wasser ist.

7. Aufschmelzrollenanordnung nach Anspruch 5 oder 6, wobei eine Menge des Arbeitsfluids (214), das innerhalb der Kammer enthalten ist, in dem Bereich von 5-50 Volumen-% der Kammer liegt.

8. Aufschmelzrollenanordnung nach Anspruch 5 oder 6, wobei eine Menge des Arbeitsfluids (214), das innerhalb der Kammer enthalten ist, in dem Bereich von 5-15 Volumen-% der Kammer liegt.

9. Aufschmelzrollenanordnung nach einem vorhergehenden Anspruch, wobei:

benachbarte Windungen der Spule (213) axial voneinander beabstandet sind; und
ein Abstandsteil (213') aus einem thermisch leitenden Material zwischen den benachbarten Windungen der Spule zwischengefügt ist.

10. Aufschmelzrollenanordnung nach einem vorhergehenden Anspruch, wobei:

benachbarte Windungen der Spule (213) axial voneinander beabstandet sind; und
ein Abstandsteil (213') aus einem thermisch leitenden Material zwischen den benachbarten Windungen der Spule zwischengefügt ist, wobei das Abstandsteil in einem gleichzeitigen thermischen Kontakt mit im Wesentlichen einer gesamten axialen Länge der inneren, zylindrischen Fläche des Hohlraums und mit im Wesentlichen einer gesamten axialen Länge der zylindrischen Außenfläche des Wärmerohrs steht.

11. Aufschmelzrollenanordnung nach Anspruch 9 oder 10, wobei die Aufschmelzrolle (212), das Abstandsteil (213') und das Wärmerohr (262) aus Aluminium hergestellt sind.

12. Aufschmelzrollenanordnung nach Anspruch 9, 10 oder 11, wobei die Aufschmelzrolle (212) aus einem thermisch leitenden Material hergestellt ist, das einen ersten Härte-Koeffizienten zeigt, wobei das Abstandsteil (213') aus einem thermisch leitenden Material hergestellt ist, das einen zweiten und geringeren Härte-Koeffizienten zeigt, und wobei das Wärmerohr (262) aus einem thermisch leitenden Material hergestellt ist, das einen dritten und geringsten Härtegrad zeigt.

13. Verfahren zum Herstellen einer Aufschmelzrollenanordnung, mit:

Bilden einer zylindrischen Aufschmelzrolle (212) mit einem zentralen, axial orientierten Innenhohlraum;
Bilden eines Wärmerohrs (262), das eine Innenkammer besitzt; und **gekennzeichnet durch**
Einsetzen des Wärmerohrs (262) in die Aufschmelzrolle (213), um das Wärmerohr ruhend koaxial innerhalb des Innenhohlraums mit einer elektrisch leitenden Heizspule (213), gewickelt in einer Spiralform, mit einer Mehrzahl von axial beabstandeten Windungen, um eine zentrale, axiale Länge einer zylindrischen Außenfläche des Wärmerohrs herum, zu platzieren;
Evakuieren der Innenkammer;
teilweises Füllen der Innenkammer mit einer Menge eines Arbeitsfluids (214); hermetisches Abdichten der Innenkammer; und
Bilden einer elektrischen Verbindung über die Heizspule (213).

14. Verfahren nach Anspruch 13, das weiterhin aufweist:

Ausbilden der Aufschmelzrolle (212) mit dem Innenhohlraum, der einen ersten Innendurchmesser besitzt;
Wickeln der Heizspule (213) so, um einen zweiten Außendurchmesser größer als der erste Durchmesser vor Einsetzen der Heizspule in den Innenhohlraum zu haben;
Verringern des zweiten Durchmessers während des Einsetzens; und
Freigeben der Heizspule (213), um den zweiten Durchmesser nach dem Einsetzen anzunehmen.

15. Verfahren nach Anspruch 13 oder 14, wobei die Menge eines Arbeitsfluids (214), enthalten innerhalb des Wärmerohrs, in dem Bereich von 5-50 Volumen-% der Innenkammer liegt.

16. Verfahren nach Anspruch 13 oder 14, wobei die Menge eines Arbeitsfluids (214), enthalten innerhalb des Wärmerohrs, in dem Bereich von 5-15 Volumen-% der Innenkammer liegt.

17. Verfahren nach einem der Ansprüche 13 bis 16, das weiterhin aufweist:

axiales Beabstanden von aufeinanderfolgenden Windungen der Spule (213); und
Zwischenfügen eines Abstandsteils (213') aus einem thermisch leitenden Material zwischen den aufeinanderfolgenden Windungen der Spule.

18. Verfahren nach einem der Ansprüche 13 bis 16, das weiterhin aufweist:

axiales Beabstanden von aufeinanderfolgenden Windungen der Spule (213); und
Zwischenfügen eines Abstandsteils (213') aus einem thermisch leitenden Material zwischen den aufeinanderfolgenden Windungen der Spule, wobei das Abstandsteil in gleichzeitigem, thermischem Kontakt mit im Wesentlichen einer gesamten axialen Länge einer zylindrischen Innenfläche des Hohlraums und mit im Wesentlichen einer gesamten axialen Länge der zylindrischen Außenfläche steht.

19. Verfahren nach Anspruch 17 oder 18, wobei die Aufschmelzrolle (212) und das Abstandsteil (213') aus Aluminium hergestellt sind.

20. Verfahren nach Anspruch 17, 18 oder 19, wobei die Aufschmelzrolle (212) aus einem thermisch leitenden Material hergestellt ist, das einen ersten Härte-Koeffizienten zeigt, und wobei das Abstandsteil (213') aus einem thermisch leitenden Material hergestellt ist, das einen zweiten und geringeren Härte-Koeffizienten zeigt, wobei das Wärmerohr (262) aus einem thermisch leitenden Material hergestellt ist, das einen dritten und geringsten Härtegrad zeigt.

Revendications

1. Ensemble à rouleau de fusion, comportant :

un rouleau de fusion cylindrique (212) fournissant une cavité creuse orientée axialement (242),
un tube de chauffe (262) ayant des extrémités opposées scellées, fournissant une chambre mise sous vide pouvant être maintenue sous vide, positionné coaxialement dans ledit rouleau de fusion, et

caractérisé par :

une bobine chauffante électriquement conductrice (213) enroulée en hélice autour d'une surface cylindrique extérieure dudit tube de chauffe, interposée coaxialement entre ladite surface cylindrique extérieure dudit tube de chauffe et ladite surface cylindrique intérieure de ladite cavité creuse, et venant en contact avec celles-ci.

2. Ensemble à rouleau de fusion selon la revendication 1, dans lequel avant l'introduction de ladite bobine (213) dans ladite cavité (242), ladite bobine a un diamètre extérieur supérieur au diamètre intérieur du rouleau de fusion, de telle sorte qu'au moins certaines spires de ladite bobine viennent en contact avec une certaine force d'une paroi cylindrique intérieure de ladite cavité creuse.

3. Ensemble à rouleau de fusion selon la revendication 1 ou 2, dans lequel ledit tube de chauffe (262) est formé en cuivre.

4. Ensemble à rouleau de fusion selon la revendication 1, 2 ou 3, dans lequel le rouleau de fusion (212) est formé en aluminium.

5. Ensemble à rouleau de fusion selon l'une quelconque des revendications précédentes, comportant un fluide de travail (214) contenu dans ladite chambre.

6. Ensemble à rouleau de fusion selon la revendication 5, dans lequel le fluide de travail (214) est de l'eau distillée.

7. Ensemble à rouleau de fusion selon la revendication 5 ou 6, dans lequel une quantité dudit fluide de travail (214) contenu dans ladite chambre est dans la plage de 5 à 50 % en volume de ladite chambre.

8. Ensemble à rouleau de fusion selon la revendication 5 ou 6, dans lequel une quantité dudit fluide de travail (214) contenu dans ladite chambre est dans la plage de 5 à 15 % en volume de ladite chambre.

9. Ensemble à rouleau de fusion selon l'une quelconque des revendications précédentes, dans lequel :

des spires voisines de ladite bobine (213) sont espacées axialement, et
une entretoise (213') d'un matériau thermiquement conducteur est interposée entre lesdites spires voisines de ladite bobine.

10. Ensemble à rouleau de fusion selon l'une quelconque des revendications précédentes, dans lequel :

des spires voisines de ladite bobine (213) sont espacées axialement, et
une entretoise (213') en un matériau électriquement conducteur est interposée entre lesdites spires voisines de ladite bobine, ladite entretoise étant en contact thermique simultané avec sensiblement une longueur axiale entière de ladite surface cylindrique intérieure de ladite cavité creuse, et avec sensiblement une longueur axiale entière de ladite surface cylindrique extérieure dudit tube de chauffe.

11. Ensemble à rouleau de fusion selon la revendication 9 ou 10, dans lequel ledit rouleau de fusion (212), ladite entretoise (213') et ledit tube de chauffe (262) sont réalisés en aluminium.

12. Ensemble à rouleau de fusion selon la revendication 9, 10 ou 11, dans lequel ledit rouleau de fusion (212) est réalisé en un matériau thermiquement conducteur présentant un premier coefficient de dureté, ladite entretoise (213') est réalisée en un matériau thermiquement conducteur présentant un deuxième coefficient de dureté inférieur, et ledit tube de chauffe (262) est réalisé en un matériau thermiquement conducteur présentant un troisième et dernier degré de dureté.

13. Procédé de fabrication d'un ensemble à rouleau de fusion, comportant les étapes consistant à :

former un rouleau de fusion cylindrique (212) ayant une cavité intérieure centrale orientée axialement,
former un tube de chauffe (262) ayant une chambre intérieure, et **caractérisé par** les étapes consistant à :

insérer ledit tube de chauffe (262) dans ledit rouleau de fusion (213) pour placer ledit tube de chauffe en appui coaxialement à l'intérieur de ladite cavité intérieure avec une bobine chauffante électriquement conductrice (213) enroulée en une spirale hélicoïdale, avec une pluralité de spires espacées axialement autour d'une longueur axiale centrale d'une surface cylindrique extérieure dudit tube de chauffe,

faire le vide dans ladite chambre intérieure,
remplir partiellement ladite chambre intérieure avec une quantité d'un fluide de travail (214),
fermer hermétiquement ladite chambre intérieure et,
fournir une connectivité électrique à travers ladite bobine chauffante (213).

14. Procédé selon la revendication 13, comportant en outre les étapes consistant à :

doter ledit rouleau de fusion (212) de ladite cavité intérieure présentant un premier diamètre intérieur,
enrouler ladite bobine chauffante (230) pour présenter un second diamètre extérieur supérieur audit premier diamètre avant l'insertion de ladite bobine chauffante dans ladite cavité intérieure,
réduire ledit second diamètre pendant ladite insertion, et
relâcher ladite bobine chauffante (230) pour prendre ledit second diamètre après ladite insertion.

15. Procédé selon la revendication 13 ou 14, dans lequel ladite quantité de fluide de travail (214) contenue dans ledit tube de chauffe est dans la plage de 5 à 50 % en volume de ladite chambre intérieure.

16. Procédé selon la revendication 13 ou 14, dans lequel ladite quantité de fluide de travail (214) contenue dans ledit tube de chauffe est dans la plage de 5 à 15 % en volume de ladite chambre intérieure.

17. Procédé selon l'une quelconque des revendications 13 à 16, comportant en outre les étapes consistant à :

espacer axialement des spires successives de ladite bobine (213) et,
interposer une entretoise (213') d'un matériau thermiquement conducteur entre lesdites spires successives de ladite bobine.

18. Procédé selon l'une quelconque des revendications 13 à 16, comportant en outre les étapes consistant à :

espacer axialement des spires successives de ladite bobine (213) et,
interposer une entretoise (213') d'un matériau thermiquement conducteur entre des spires successives de ladite bobine, ladite entretoise étant en contact thermique simultané avec sensiblement une longueur axiale entière d'une surface cylindrique intérieure de ladite cavité et avec sensiblement une longueur axiale entière de ladite surface cylindrique extérieure.

19. Procédé selon la revendication 17 ou 18, dans lequel ledit rouleau de fusion (212) et ladite entretoise (213') sont réalisés en aluminium.

20. Procédé selon la revendication 17, 18 ou 19, dans lequel ledit rouleau de fusion (212) est réalisé en un matériau thermiquement conducteur présentant un premier coefficient de dureté, ladite entretoise (213') est réalisée en un matériau thermiquement conducteur présentant un deuxième coefficient de dureté inférieur, et ledit tube de chauffe (262) est réalisé en un matériau thermiquement conducteur présentant un troisième et dernier degré de dureté.

FIG. 1

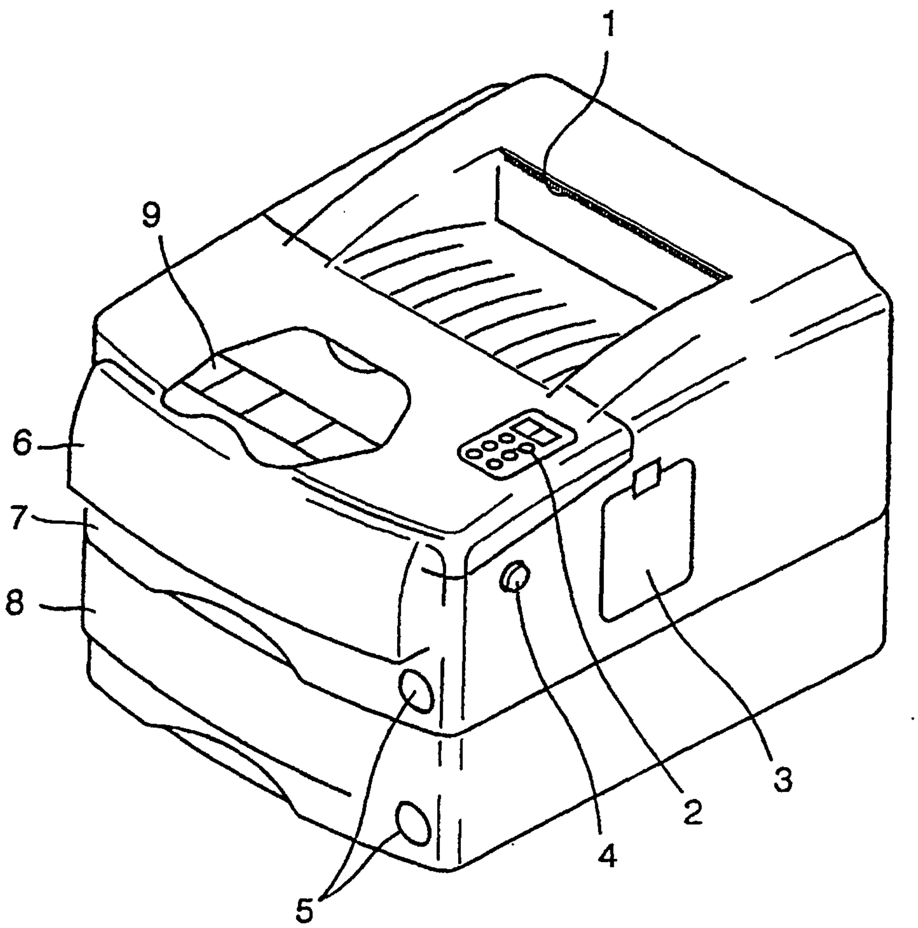


FIG. 2 (PRIOR ART)

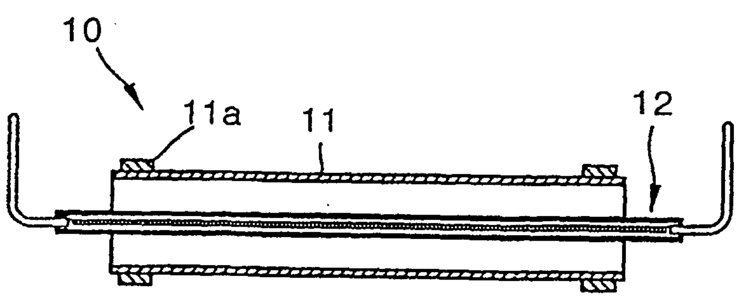


FIG. 3 (PRIOR ART)

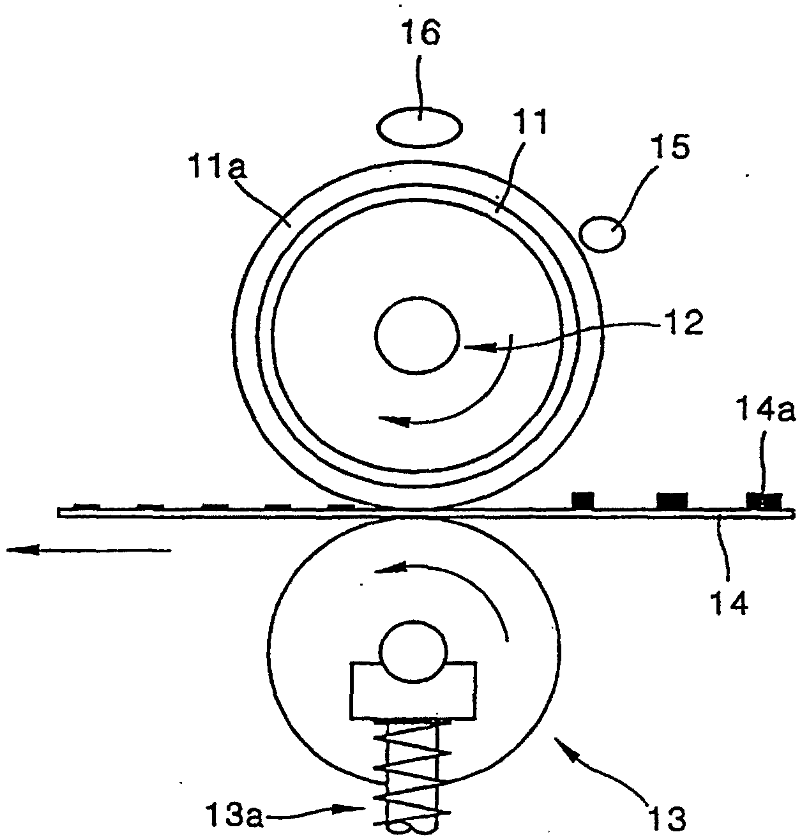


FIG 4 (PRIOR ART)

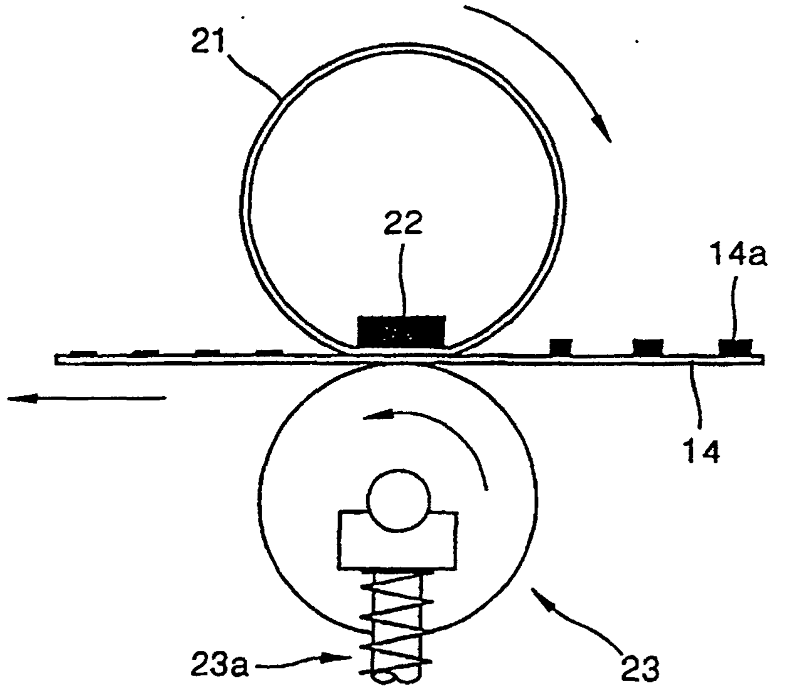


FIG 5

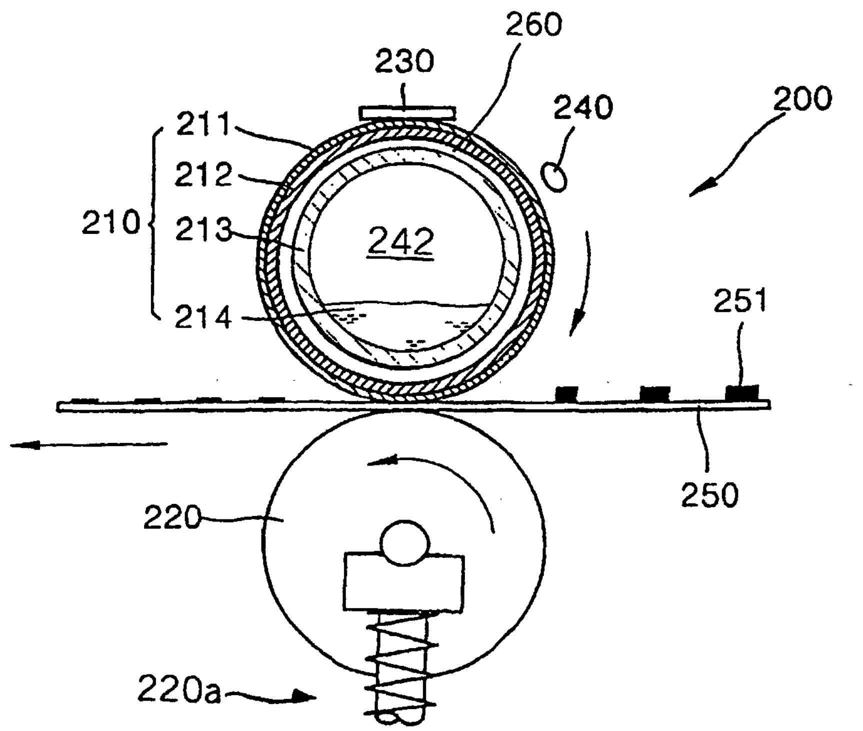


FIG. 6

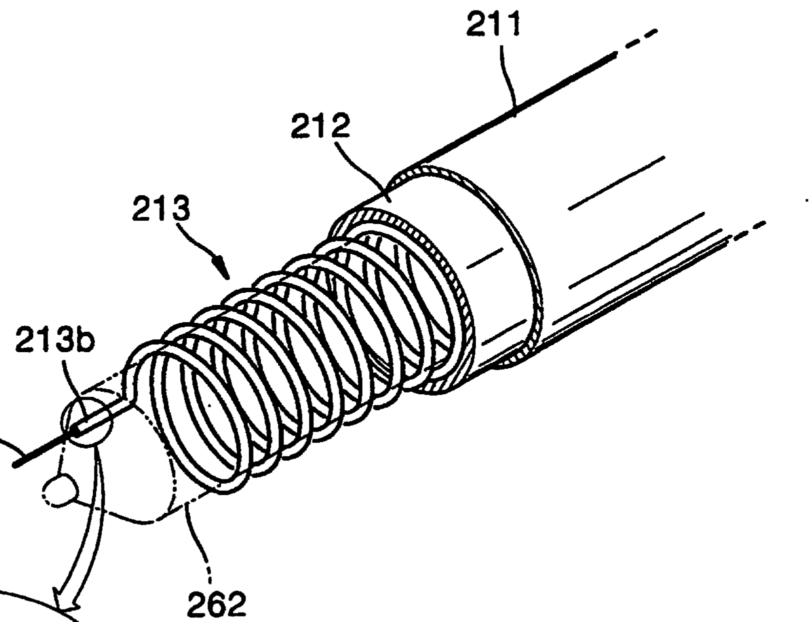
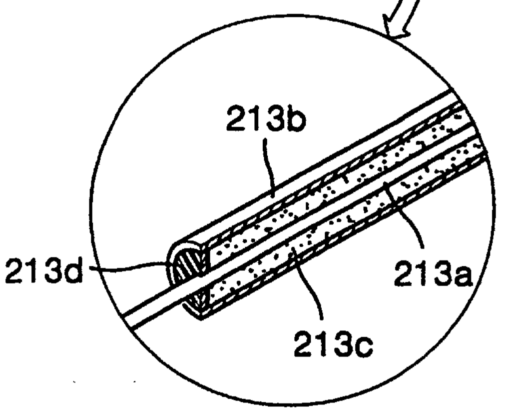


FIG. 6A



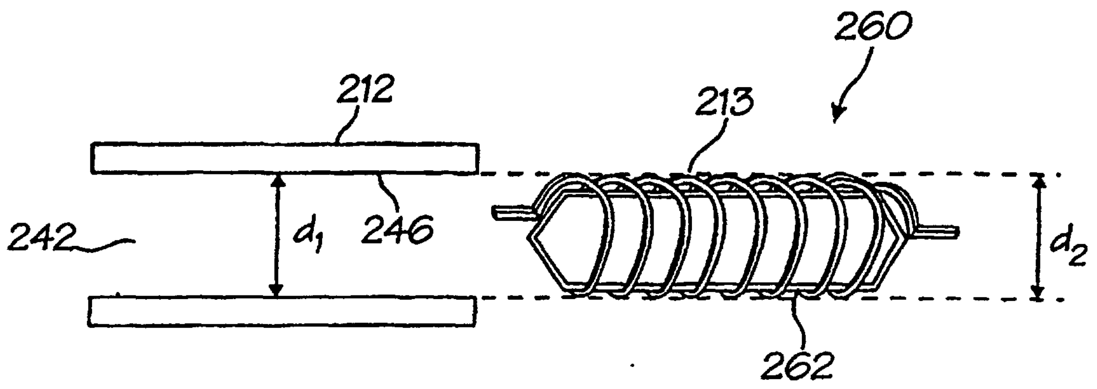


FIG. 6B

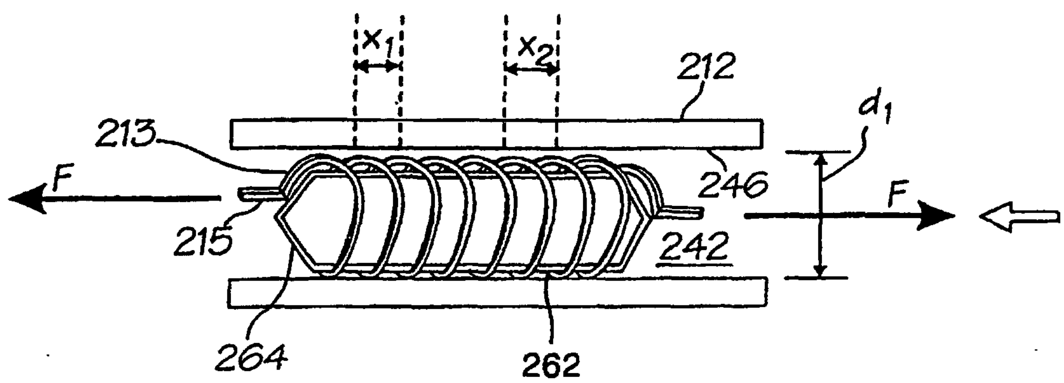


FIG. 6C

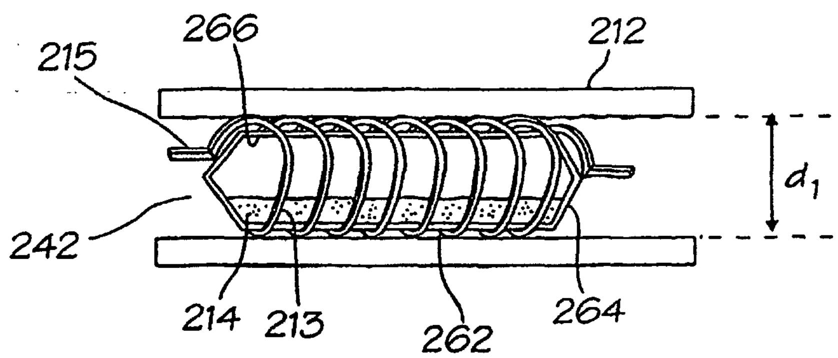


FIG. 6D

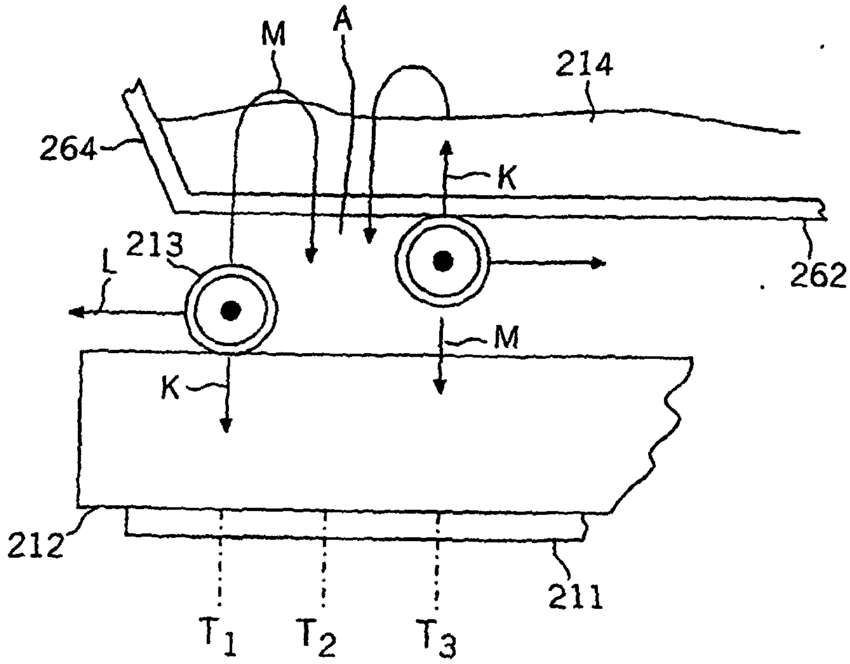

M
A
214
264
K
213
L
262
M
K
212
211
T1
T2
T3

FIG. 8

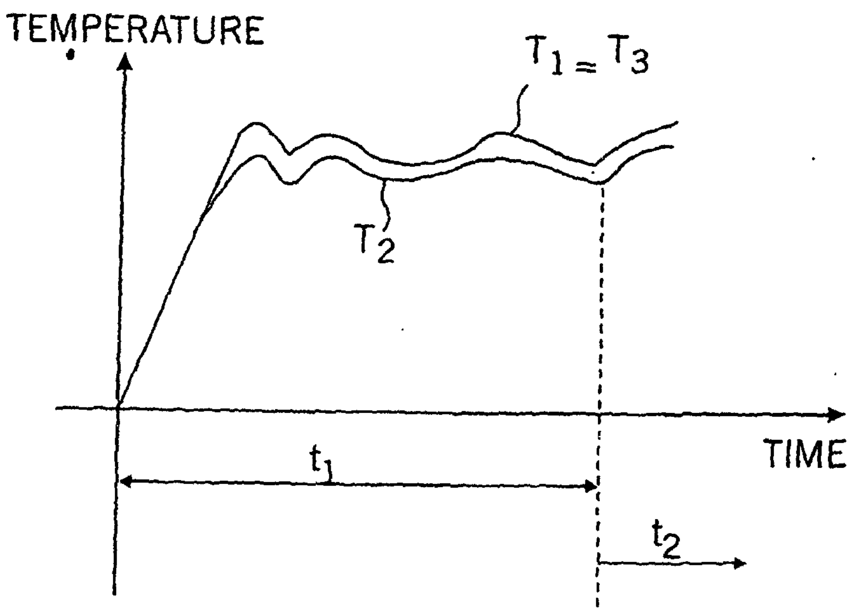

TEMPERATURE
T1 = T3
T2
TIME
t1
t2

FIG. 9

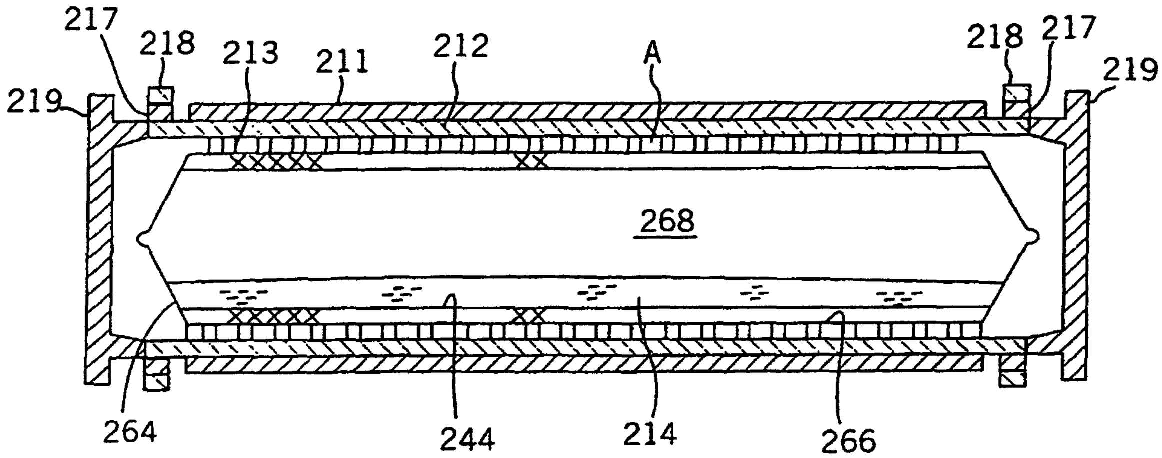

217
218
213
211
212
A
218
217
219
219
268
264
244
214
266

FIG. 7

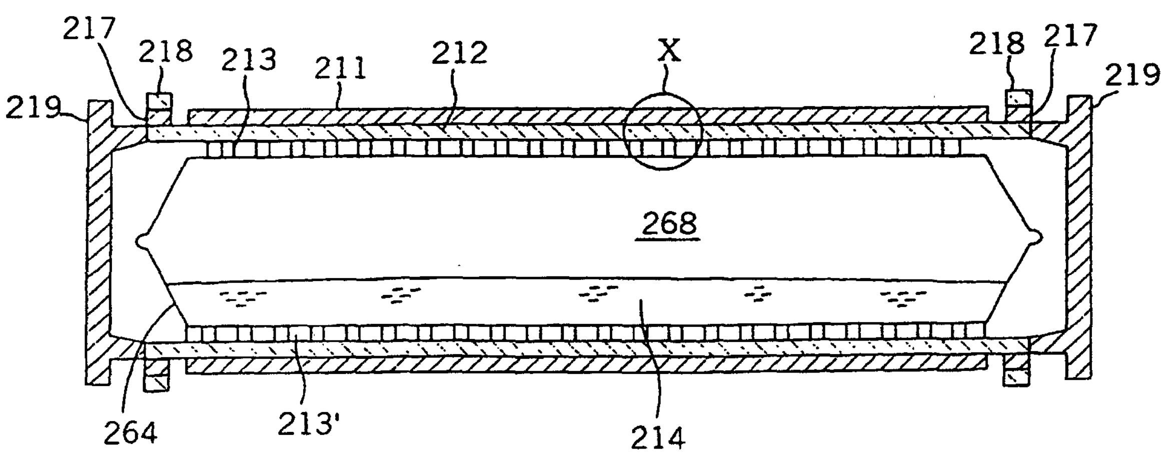

217
218
213
211
212
X
218
217
219
219
268
264
213'
214

FIG. 10

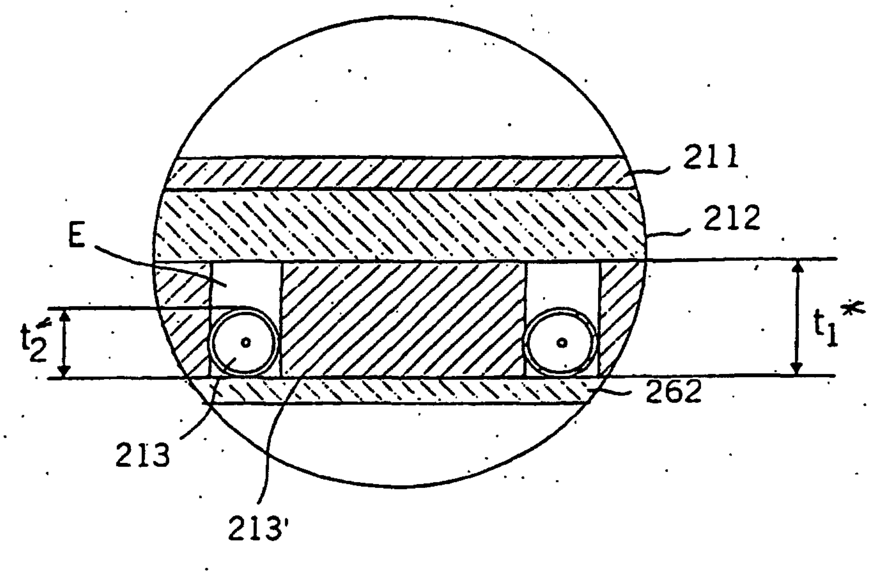


FIG. 11

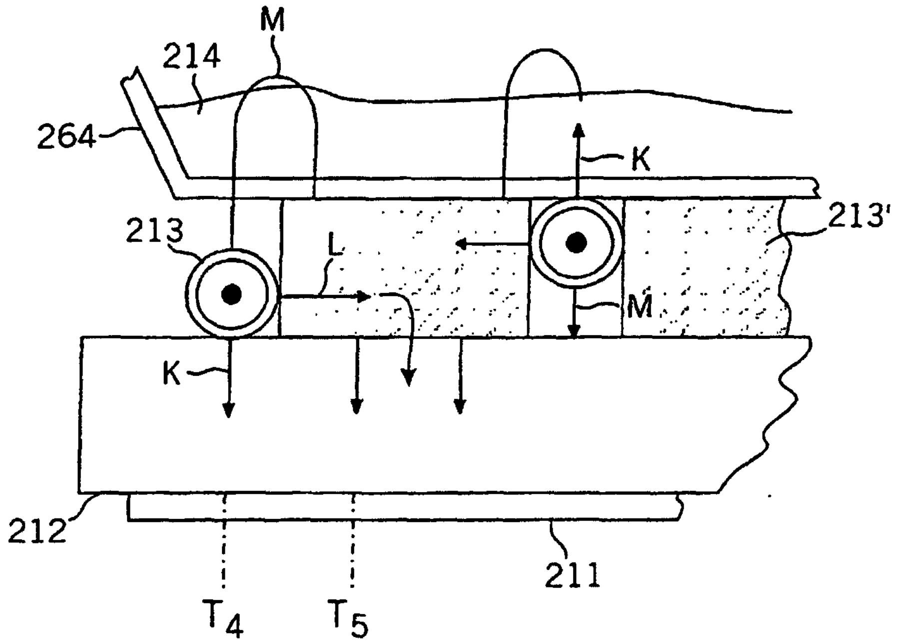


FIG. 12

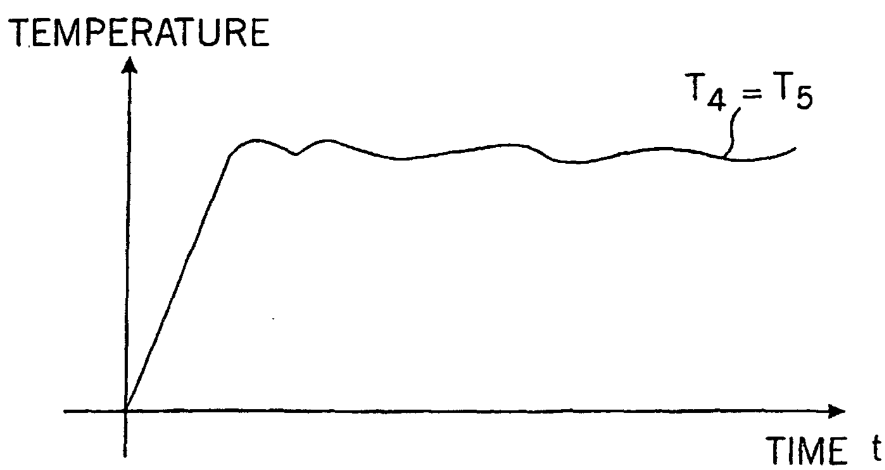


FIG. 13

FIG 14

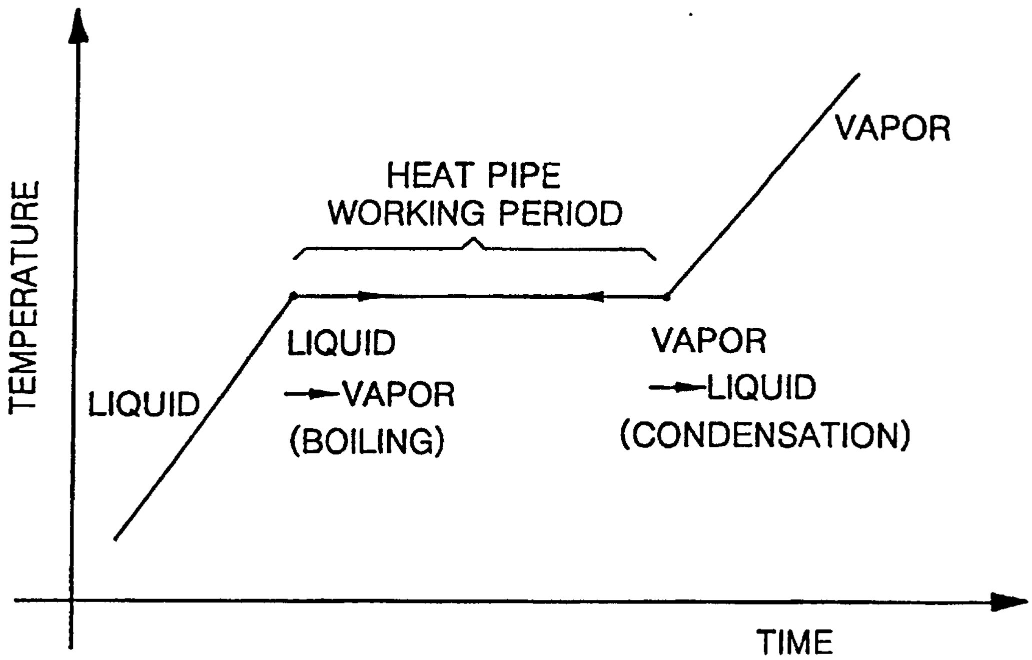

TEMPERATURE
HEAT PIPE
WORKING PERIOD
VAPOR
LIQUID
LIQUID
→VAPOR
(BOILING)
VAPOR
→LIQUID
(CONDENSATION)
TIME

FIG. 15

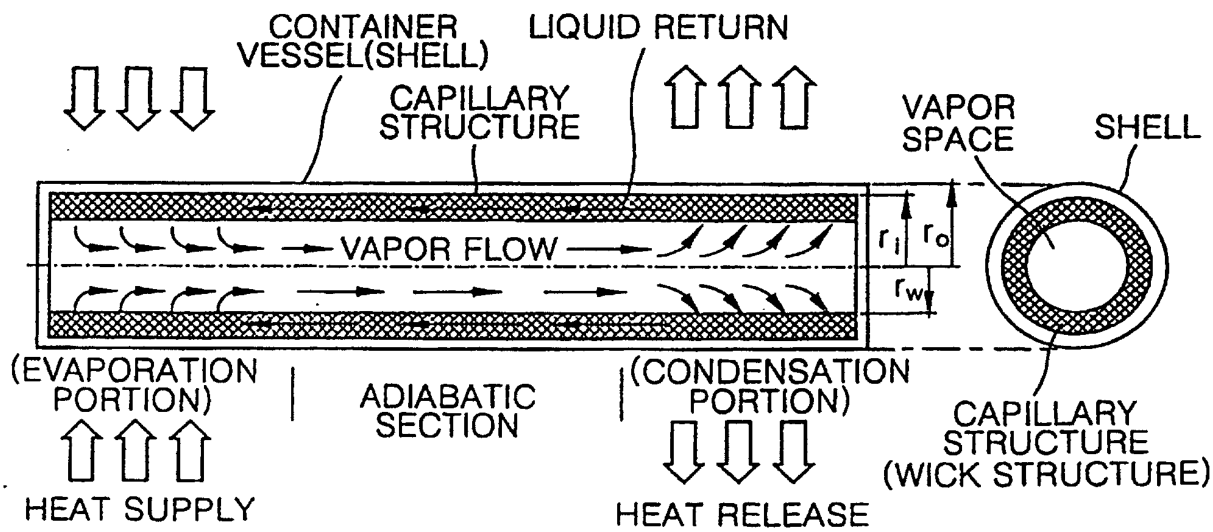

CONTAINER
VESSEL(SHELL)
LIQUID RETURN
CAPILLARY
STRUCTURE
VAPOR
SPACE
SHELL
VAPOR FLOW
r i
r o
r w
(EVAPORATION
PORTION)
ADIABATIC
SECTION
(CONDENSATION
PORTION)
CAPILLARY
STRUCTURE
(WICK STRUCTURE)
HEAT SUPPLY
HEAT RELEASE

FIG. 16

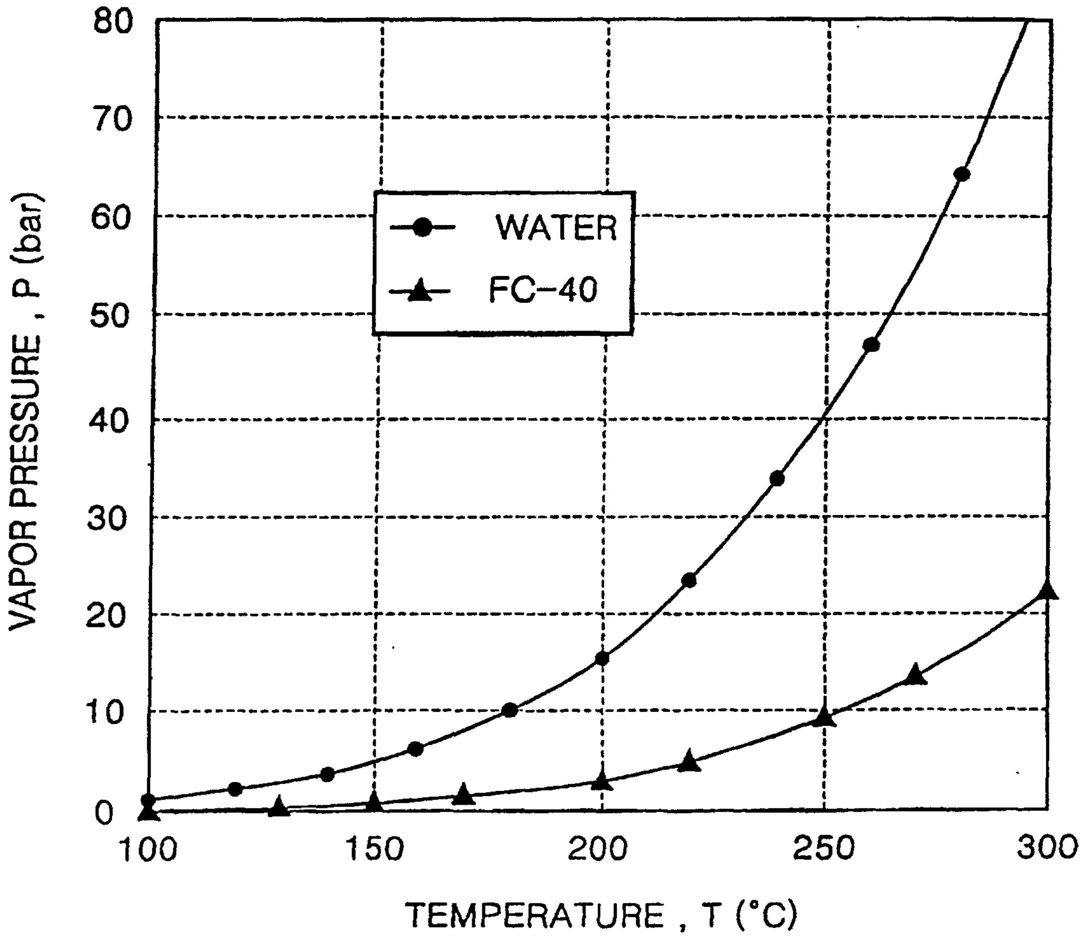

80
70
60
50
40
30
20
10
0
VAPOR PRESSURE , P (bar)
WATER
FC-40
100
150
200
250
300
TEMPERATURE , T (°C)

FIG. 17

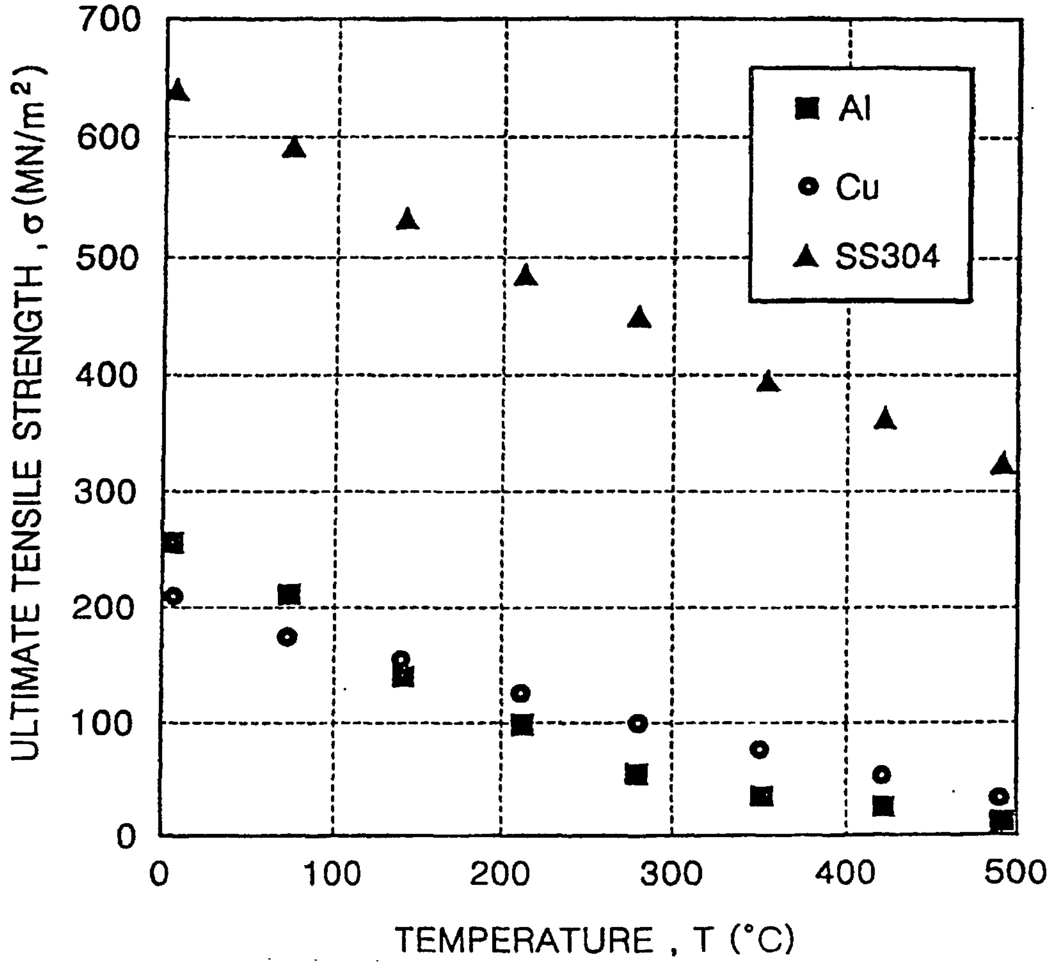

700
600
500
400
300
200
100
0
0
100
200
300
400
500
ULTIMATE TENSILE STRENGTH , σ (MN/m²)
TEMPERATURE , T (°C)
Al
Cu
SS304

FIG. 18A

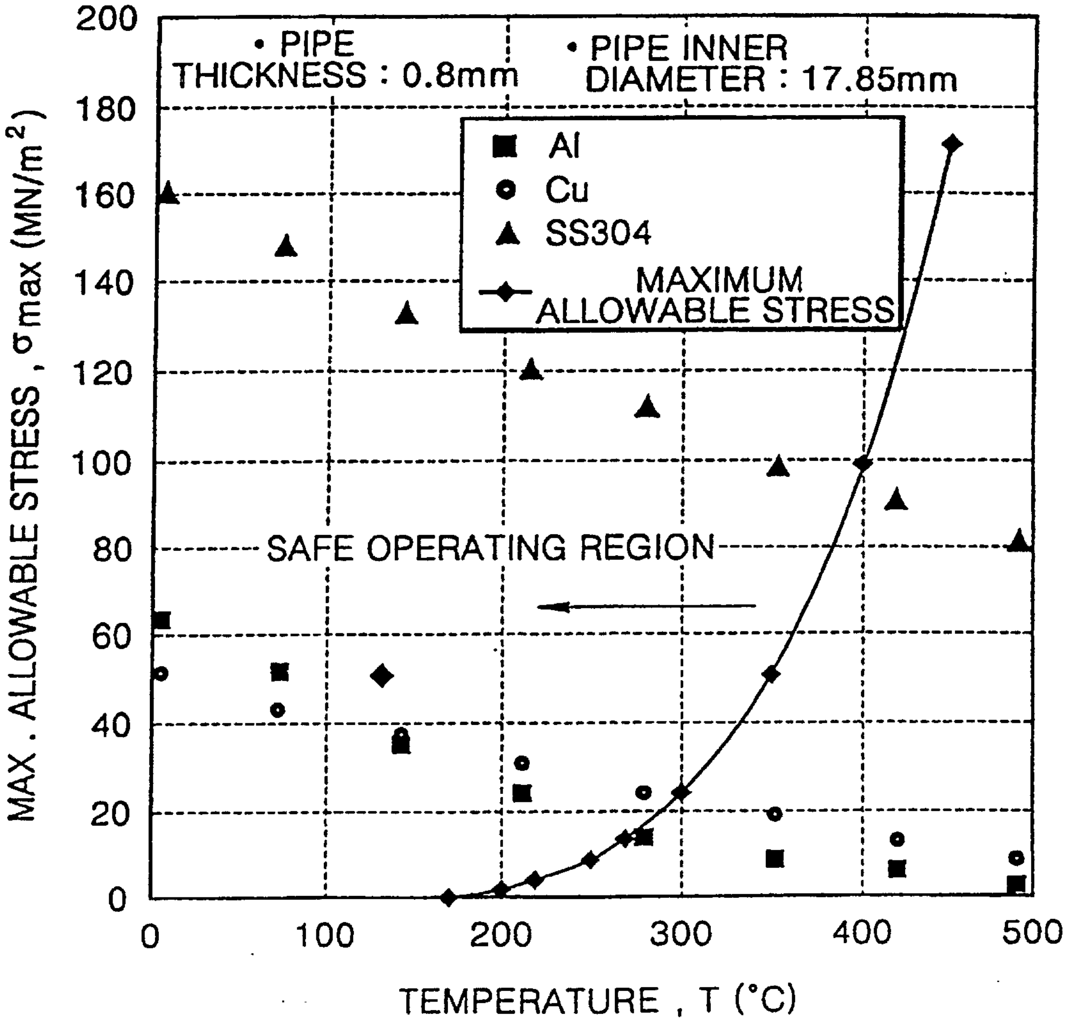

• PIPE
THICKNESS : 0.8mm
• PIPE INNER
DIAMETER : 17.85mm
Al
Cu
SS304
MAXIMUM
ALLOWABLE STRESS
SAFE OPERATING REGION
MAX . ALLOWABLE STRESS , σmax (MN/m2)
TEMPERATURE , T (°C)
0
20
40
60
80
100
120
140
160
180
200
0
100
200
300
400
500

FIG. 18B

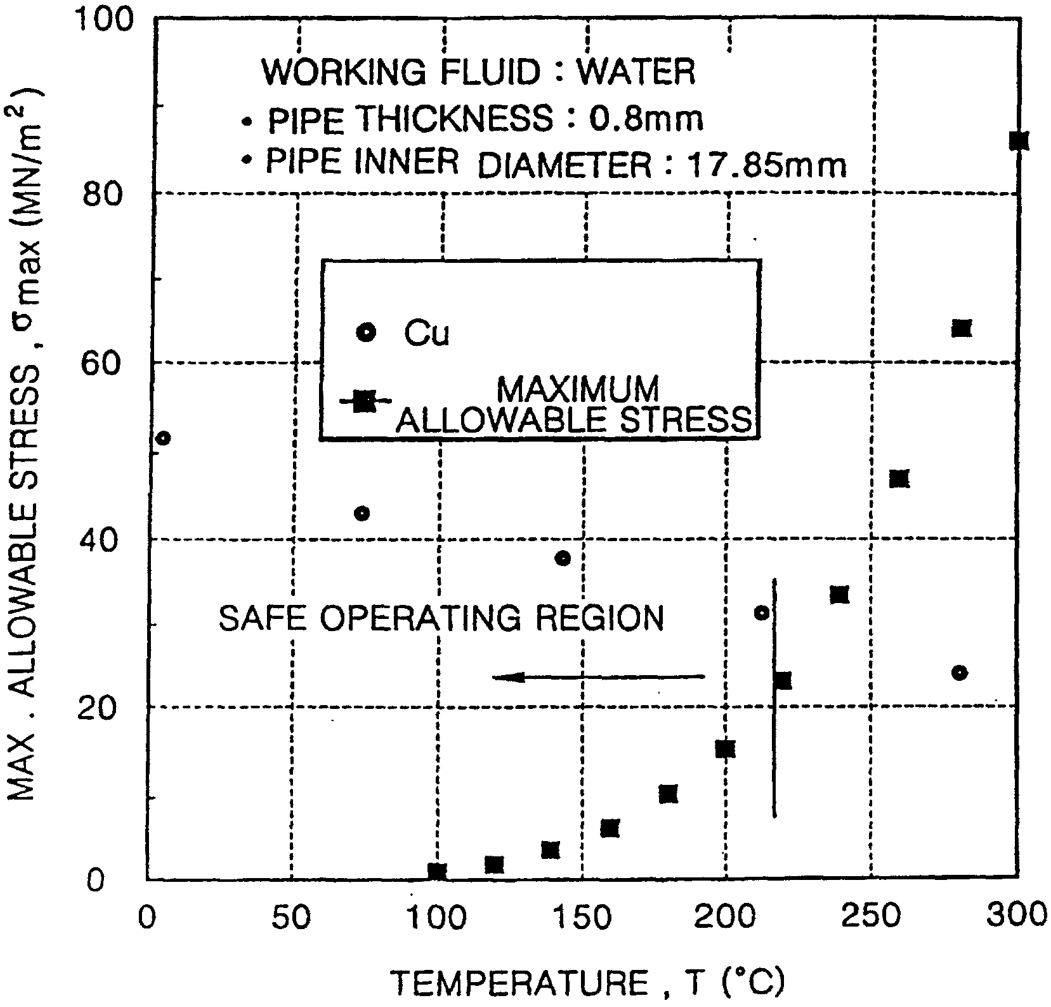

WORKING FLUID : WATER
• PIPE THICKNESS : 0.8mm
• PIPE INNER DIAMETER : 17.85mm
Cu
MAXIMUM ALLOWABLE STRESS
SAFE OPERATING REGION
MAX . ALLOWABLE STRESS , σmax (MN/m2)
TEMPERATURE , T (°C)
0
20
40
60
80
100
0
50
100
150
200
250
300

FIG. 19A

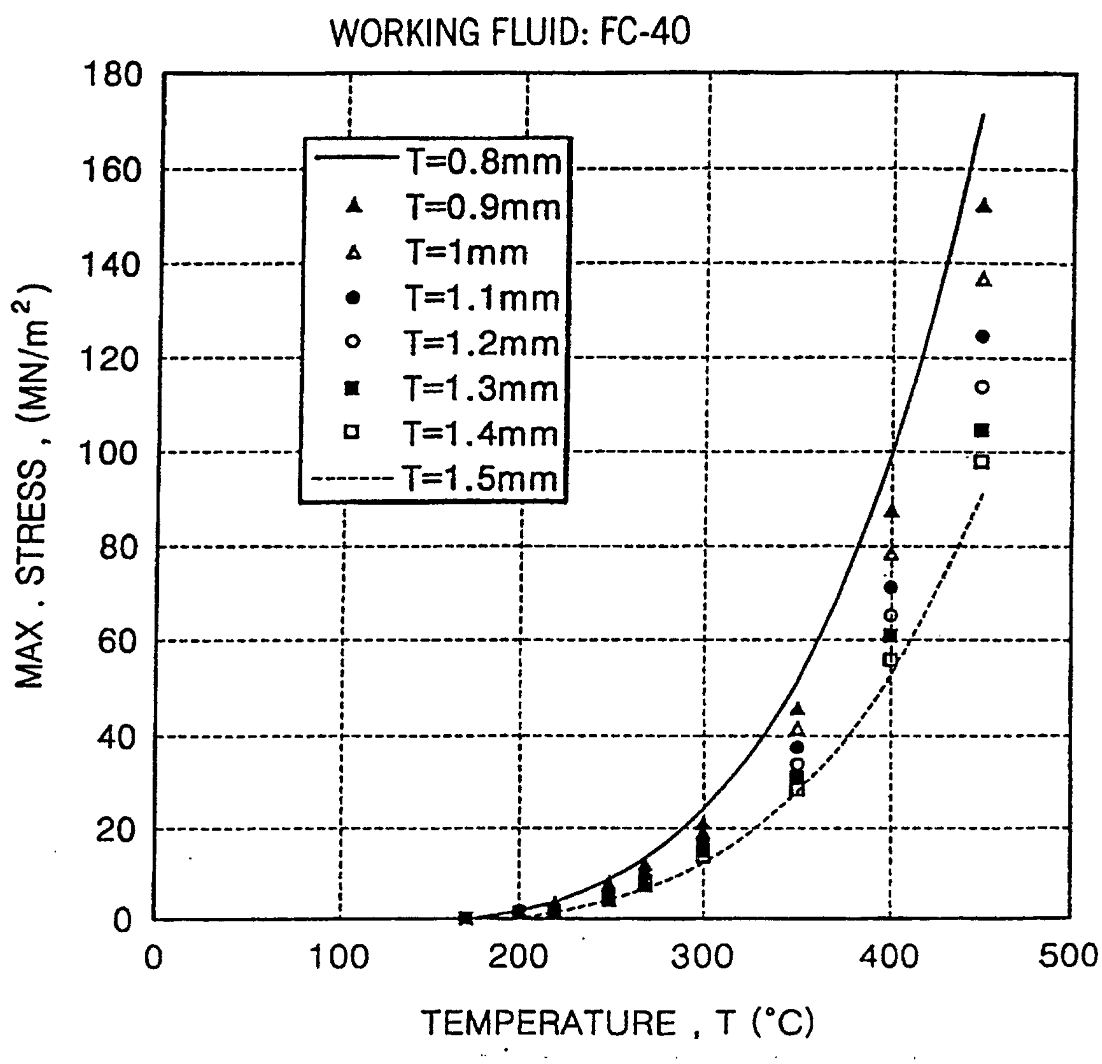

WORKING FLUID: FC-40
T=0.8mm
T=0.9mm
T=1mm
T=1.1mm
T=1.2mm
T=1.3mm
T=1.4mm
T=1.5mm
MAX . STRESS , (MN/m^2)
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
TEMPERATURE , T (°C)

FIG. 19B

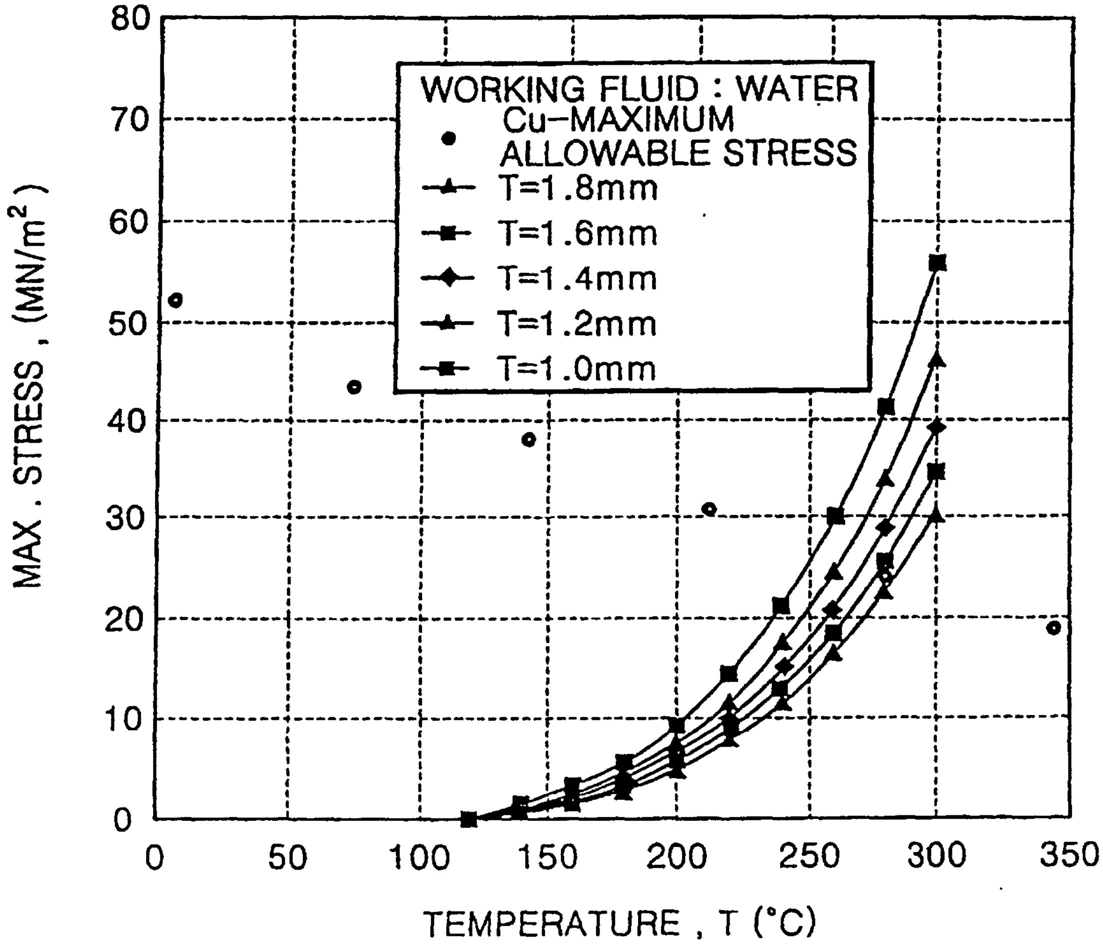

WORKING FLUID : WATER
Cu–MAXIMUM ALLOWABLE STRESS
T=1.8mm
T=1.6mm
T=1.4mm
T=1.2mm
T=1.0mm
MAX . STRESS , (MN/m²)
TEMPERATURE , T (°C)
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
300
350

FIG. 20

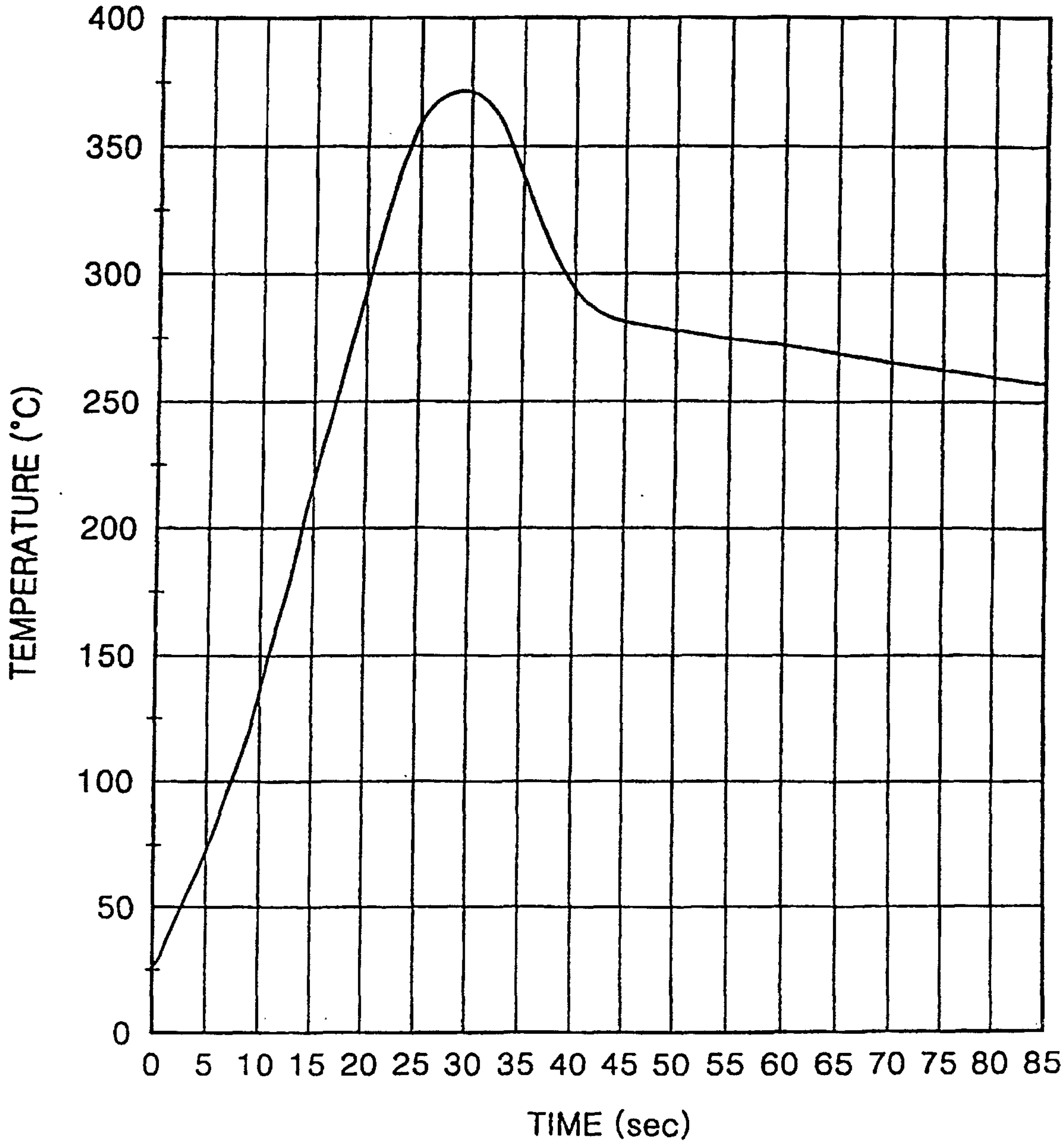
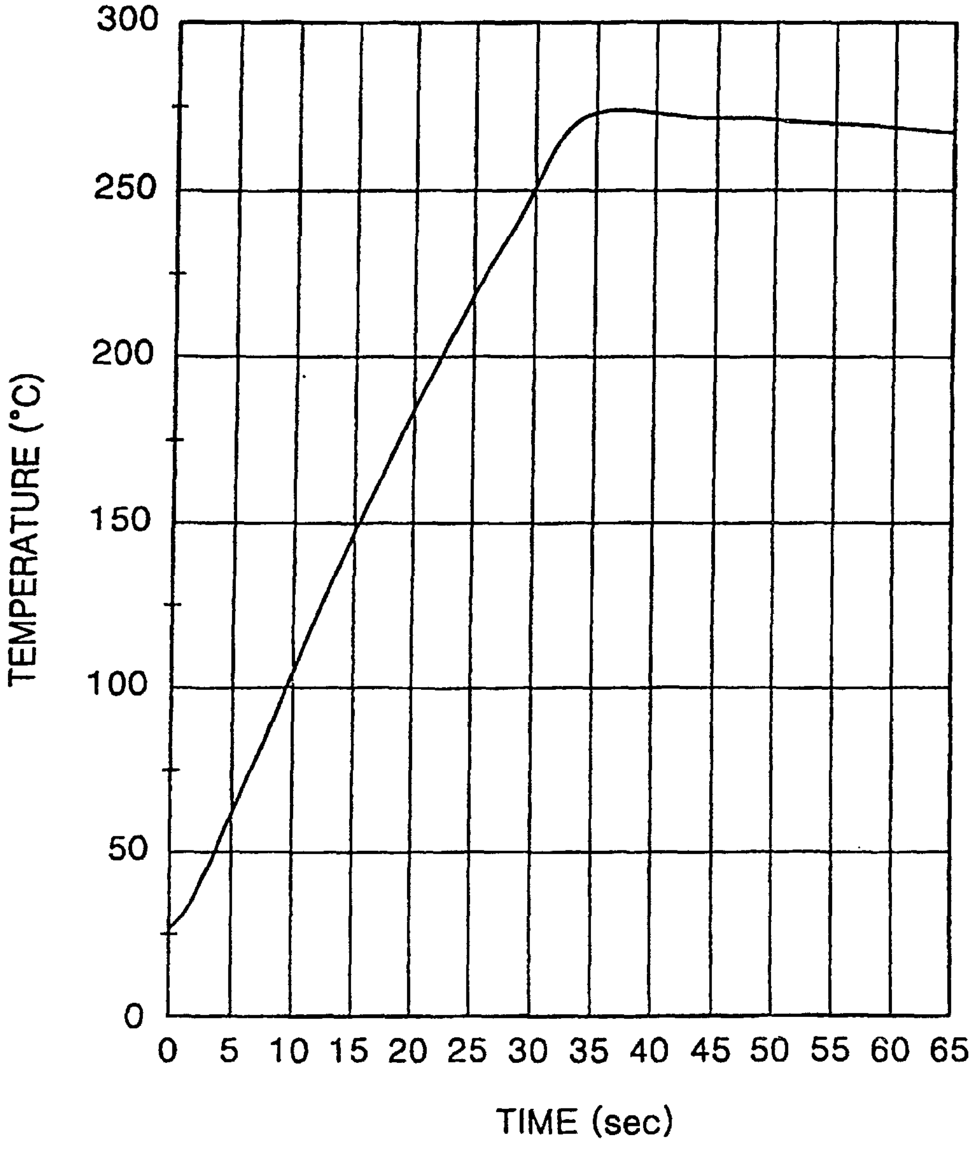

400
350
300
250
200
150
100
50
0
TEMPERATURE (°C)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
TIME (sec)

FIG. 21


300
250
200
150
100
50
0
TEMPERATURE (°C)
0 5 10 15 20 25 30 35 40 45 50 55 60 65
TIME (sec)