

Flat heating element and use of flat heating elements

The invention refers to a flat heating element, more particularly a resistance-heating element, and uses of flat heating elements.

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Resistance-heating elements are used in different sectors to generate heat. As a rule, these heating elements require high voltages in the heating element in order to generate a sufficiently high temperature. These high voltages, however, can constitute safety risks, particularly when used to heat media or when in contact with the human
10 body. Moreover, because of the materials used in them, most traditional resistance-heating elements are suitable only for low temperatures, particularly in long-term operation. Other proposals of the prior art require a complex constitution of the resistance-heating element und hence limit possible applications of the resistance-heating element.

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It is the objective of the present invention to provide a heating element with which a high output per unit area and thus high temperatures can be generated even in long-term operation while low voltages prevail in the heating element. In addition, the heating element should be versatile in its applications and simple to provide with
20 contact terminals.

The invention further refers to a heatable pipe in which a resistance-heating element is employed.

25 Pipes are extensively employed, for instance, to conduct fluid media. When such pipes for instance are laid underground or as open-air piping in cold regions, the risk exists that the medium present in the pipe solidifies because of the low temperatures, and the pipe clogs.

30 It is a further objective of the invention, therefore, to provide a pipe that can be heated by simple means and used in a versatile manner.

The invention further relates to a heatable transportation device for media.

Media such as gases or liquids often are transported in tanks mounted on railway cars or on trucks. At low ambient temperatures, the medium in the tank can freeze and thus
5 may even damage the tank. The installation of heating elements in such cars is highly demanding with respect to the heating element as well as to the heat transfer that can occur between the heating element and the car. Dangerous substances sometimes are transported in such tanks. It is important then that the heating element will not lead to any local temperature increase. But also a failure of the heating element, for instance
10 as a result of its detachment from the tank, must be avoided in order to prevent freezing of the medium.

It is a further objective of the present invention, therefore, to provide a transportation device for media in which during transport a medium can be kept at a predetermined
15 temperature, without creating safety risks such as freezing, an explosion or a fire.

The invention further refers to a heat roller, particularly for its use as a copying or foil-coating roller.

20 In many areas of heating technology, it is necessary to provide a roller which can be heated to a certain temperature. Up to now such heat rollers have been produced with heating elements having resistance wires embedded in an insulating mass. Another operating mode of heat rollers, for instance in copiers, is the installation of a halogen emitter in the roller. Both of these versions have the disadvantage of being either very
25 expensive in their manufacture or exhibiting a poor efficiency of heat transfer.

The present invention is based on the objective to provide a heat roller of simple design that can be operated with low voltage and at the same time has a high heat transfer efficiency. The heat roller should further be versatile in its applications.

The invention is based on the realization that these objectives can be reached by a resistance-heating element in which the heating current flows in an optimum way through a suitable resistive mass.

- 5 The invention is further based on the realization that the further objectives can be reached in particular by a pipe, a transportation device and a heat roller provided with a resistance-heating element, where the resistance-heating element comprises a suitable resistive mass, the heating current flows in an optimum way through this mass, the heating element is of flat shape and guarantees a heat transfer that is uniform
10 across the area.

According to the invention, the objectives are reached by a flat heating element comprising a thin resistance layer containing an intrinsically electroconductive polymer and at least two flat electrodes arranged on one side of the resistance layer at a
15 distance from each other.

In the heating element according to the invention, the resistance layer contains an intrinsically electroconductive polymer.

- 20 These polymers which, according to the invention, are used in the resistance layer have a constitution such that the current flows along the polymer molecules. Owing to the polymer structure, the heating current is conducted through the resistance layer along the polymers. Because of the electric resistance of the polymers, heat is generated which can be transferred to an object to be heated. Here the heating current
25 cannot follow the shortest pathway between the two electrodes but follows the structure of the polymer arrangement. Thus, the length of the current path is predetermined by the polymers, so that even in the instance of small layer thicknesses, relatively high voltages can be applied without causing a voltage breakdown. Even in the instance of high currents such as making currents, one must not be afraid of a
30 burn-out. Moreover, the distribution of the current in the first electrode and its subsequent conduction along the polymer structure in the resistance layer leads to a

homogeneous temperature distribution within the resistance layer. This distribution arises immediately after applying voltage to the electrodes.

Because of the polymers employed according to the invention, the resistance-heating element can be operated even at high voltages, for instance line voltage. As the attainable heating power increases with the square of operating voltage, the resistance-heating element according to the invention can yield high heating power and hence high temperatures. According to the invention, the current density is minimized because a relatively long current path is provided along the electroconductive polymers or because at least two zones electrically in series which contain the intrinsically electroconductive polymer used according to the invention are created.

Moreover, the electroconductive polymers used according to the invention exhibit long-term stability. This stability is explained above all by the fact that the polymers are ductile, so that a rupture of the polymer chains and thus interruption of the current path will not occur when the temperature is raised. The polymer chains are unharmed even after repeated temperature fluctuation. In conventional resistance-heating elements, to the contrary, where conductivity is created, for instance, by carbon black skeletons, such a thermal expansion would lead to interruption of the current path and hence to overheating. This would lead to a strong oxidation and to burn-out of the resistance layer. The intrinsically electroconductive polymer used according to the invention is not subject to such aging phenomena.

The intrinsically conductive polymers used according to the invention resist aging even in reactive environments such as air oxygen. Moreover, current conduction through the resistive mass is of the electronic conduction type. Hence even an autodestruction of the resistance layer by electrolysis reactions caused by electric currents will not occur in the resistance-heating element according to the invention. In the resistance-heating element according to the invention, time-dependent drops in heating power per unit area are very small and approximately zero, even at temperatures as high as 500 °C for instance, and at heating powers per unit area as high as 50 kW/m² for instance.

Due to the use of intrinsically electroconductive polymers, the resistance layer as a whole which is used according to the invention presents a homogeneous structure that permits a heating that is uniform across the entire layer.

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According to the invention, contact to the resistance-heating element is provided by two electrodes which preferably consist of a material of high electric conductivity and are arranged on one side of the resistance layer. This type of contact arrangement makes it possible to use the mode of operation of the intrinsically conductive polymers used according to the invention in a particularly advantageous way. The applied current first spreads within the first electrode, then crosses the thickness of the resistance layer along the polymer structure, and finally is conducted to the second contacted electrode. Therefore, the current path is additionally extended over that present in a structure where the resistance layer is sandwiched between the two electrodes. Because of this flow of the current, the thickness of the resistance layer can be kept small.

The heating element according to the invention has the further advantage of being versatile in its applications. The electrodes are provided with contacts on one side of the resistance layer. The opposite side of the resistance layer therefore is free of contact terminals, and hence can be of flat shape. Such a flat surface permits a direct application to the body to be heated. An ideal heat transfer becomes possible since the contact area between the resistance-heating element and the body to be heated is not disrupted by contact terminals.

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In a preferred embodiment, a flat floating electrode is arranged on the side of the resistance layer opposite to the two flat electrodes.

In the spirit of the invention, an electrode is called floating when it is not connected to the source of current. It can have an insulation preventing electric contact with a source of current.

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This floating electrode supports the flow of current through the resistance layer. In this embodiment the current spreads within the first electrode, crosses the thickness of the resistance layer to reach the floating electrode on the opposite side, is conducted further within this electrode, and finally flows through the thickness of the resistance
5 layer to the other electrode that is arranged on the same side of the resistance layer as the first electrode.

In this embodiment of the heating element, the current flows through the thickness of the resistance layer, essentially in a direction normal to its surface. Essentially two
10 zones develop within the resistance layer. Within the first zone, the current flows essentially vertically from the first contacted electrode to the floating electrode, while within the second zone, it flows essentially vertically from the floating electrode to the second contacted electrode. Thus, a series arrangement of several resistances is attained by this arrangement. This effect implies that the partial voltage prevailing in
15 the individual zones is smaller than the applied voltage. Thus, in this embodiment of the invention the voltage prevailing in the individual zones is half of the applied voltage. Because of the low voltage prevailing in the resistance layer, safety risks can be avoided with the heating element according to the invention, and possible applications thus are manifold. The heating element can then also be used in devices
20 where it comes in immediate contact with a medium to be heated, or must be touched by the persons which operate or use the device.

Moreover, the gap provided between the contacted electrodes acts as an additional resistance arranged in parallel. With air as the insulator in this gap, the resistance will
25 be determined by the mutual distance of the electrodes and thus by the surface resistance of the resistance layer.

The electrodes and the floating electrode preferably have a good thermal conductivity. This can exceed 200 W/m·K, preferably 250 W/m·K. Local overheating can rapidly
30 be neutralized by this good thermal conductivity in the electrodes. An overheating is thus possible only in the direction of layer thickness, but has no negative effects because of the small layer thickness that can be realized in the resistance-heating

element according to the invention. It is a further advantage of the resistance-heating element that even a local temperature increase provoked from outside, e.g., from the body to be heated, can be balanced in an ideal way by the resistance-heating element.

5 The electrodes and the floating electrode are preferably made of a material having a high electric conductivity. Thus, the specific electric resistance of the electrodes may be less than $10^{-4} \Omega\cdot\text{cm}$, and preferably less than $10^{-5} \Omega\cdot\text{cm}$. Suitable materials are aluminum and copper, for instance. By selecting such an electrode material it is guaranteed that the current applied is conducted further within the flat electrode, i.e.,
10 spreads within it, before passing through the resistance layer. This leads to a uniform flow of the heating current through the resistance layer and thus a uniform and essentially complete heating of the resistance layer. Such a resistance-heating element therefore is able to generate and transfer heat in a uniform way. By selecting such an electrode material it is possible in particular to fabricate large resistance-heating
15 elements without a need for voltage supply to a number of spots along the length or width of the electrodes. Therefore, power supply lines need not be installed along the surface. According to the invention, such multiple contacts will only be selected for embodiments in which the resistance-heating element covers a large area or length, for instance areas larger than 60 cm^2 , preferably larger than 80 cm^2 . The limiting size
20 of the resistance-heating element above which it becomes meaningful to provide multiple contact points depends, not only on the electrode material selected, but also on the place of the contacts. Thus, multiple contact points may not be required even for areas larger than those mentioned above when the electrode is accessible in its surface midpoint and can be provided with a contact there.

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The size of the resistance-heating element that can be operated with single contacts also depends on the thickness of the electrodes selected. According to one embodiment, the electrodes and the floating electrodes have a thickness of 50 to 150 μm , preferably 75 to 100 μm each. These small layer thicknesses are also advantageous in
30 that the heat produced by the resistance-heating element can readily be transferred from them. Moreover, thin electrodes are more flexible, so that a detachment of the

electrodes from the resistance layer and thus an interruption of the electrical contact during thermal expansion of the resistance layer will be avoided.

According to the invention, the resistance layer is thin. Its thickness has a lower limit
5 that merely depends on the breakdown voltage, and is preferably 0.1 to 2 mm, preferably 1 mm. A small layer thickness of the resistance layer offers the advantage of enabling a short heat-up time, rapid heat transfer and high heating power per unit area. However, such a layer thickness is only possible with a resistance-heating element according to the invention. On one hand, the current path within the resistance layer is
10 predetermined by the polymers used according to the invention, and can be sufficiently long to prevent voltage breakdown, even when the layer thicknesses are small. On the other hand, the unilateral contact arrangement of the resistance-heating element permits subdivision of the resistance layer into zones of lower voltage, which additionally reduces the risk of breakdown.

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The advantages of the resistance-heating element according to the invention are further enhanced when the resistance layer has a positive temperature coefficient (PTC) of its electric resistance. This leads to an effect of automatic regulation with respect to the highest attainable temperature. This effect occurs, since the flow of
20 current through the resistive mass is adjusted as a function of temperature because of the PTC of the resistance layer. The current becomes lower the higher the temperature, until at a particular thermal equilibrium it has become immeasurably small. A local overheating and melting of the resistive mass can therefore be prevented reliably. This effect of automatic regulation is very important for the
25 heating element according to the invention, since a local temperature rise may occur, for instance, when the heating element according to the invention has insufficient contact with a body to be heated, and hence a low heat transfer.

Selecting a PTC material for the resistance layer also implies, therefore, that as a
30 result, the entire resistance layer is heated to essentially the same temperature. This enables uniform heat transfer, which can be essential for particular applications of the resistance-heating element.

According to the invention, the resistance layer can be metallized on its surfaces facing the electrodes and, if present, the floating electrode. By metallization, metal adheres to the surface of the resistance layer and thus improves the flow of current
5 between the electrodes or the floating electrode and the resistance layer. Moreover, in this embodiment the heat transfer from the resistance layer to the floating electrode and hence to the body or object to be heated is also improved. The surface can be metallized by spraying of metal. Such a metallization is possible only with the material of the resistance layer that is used according to the invention. A costly
10 metallization step, for instance by metal electroplating, hence is superfluous and considerably reduces the manufacturing costs.

The intrinsically electroconductive polymer is preferably produced by doping of a polymer. The doping can be a metal or semimetal doping. In these polymers the
15 defect carrier is chemically bound to the polymer chain and generates a defect. The doping atoms and the matrix molecule form a so-called charge-transfer complex. During doping, electrons from filled bands of the polymer are transferred to the dopant. On account of the electronic holes thus generated, the polymer takes on semiconductor-like electrical properties. In this embodiment, a metal or semimetal
20 atom is incorporated into or attached to the polymer structure by chemical reaction in such a way that free charges are generated which enable the flow of current along the polymer structure. The free charges are present in the form of free electrons or holes. In this way an electronic conductor arises.

25 Preferably, for its doping the polymer was mixed with such an amount of dopant that the ratio of atoms of the dopant to the number of polymer molecules is at least 1:1, preferably between 2:1 and 10:1. With this ratio it is achieved that essentially all polymer molecules are doped with at least one atom of the dopant. The conductance of the polymers and hence that of the resistance layer as well as the temperature
30 coefficient of resistance of the resistance layer can be adjusted by selecting the ratio.

The intrinsically electroconductive polymer used according to the invention can be employed as material for the resistance layer in the resistance-heating element according to the invention, even without graphite addition, but according to a further embodiment, the resistance layer may additionally contain graphite particles. These particles can contribute to the conductivity of the complete resistance layer, are preferably not in mutual contact, and in particular do not form a reticular or skeletal structure. The graphite particles are not solidly bound into the polymer structure but are freely mobile. When a graphite particle is in contact with two polymer molecules, the current can jump via the graphite from one chain to the next. The conductivity of the resistance layer can be further raised in this way. On account of their free mobility in the resistance layer, the graphite particles can also move to the surface of this layer and bring about an improvement of its contact with the electrodes or with the floating electrode.

The graphite particles are preferably present in an amount of at most 20 vol.%, and particularly preferably in an amount of at most 5 vol.% relative to the total volume of the resistance layer, and have a mean diameter of at most 0.1 μm . With this small amount of graphite and the small diameter, formation of a graphite network which would lead to current conduction through these networks can be avoided. It is thus guaranteed that the current essentially continues to flow by electronic conduction via the polymer molecules, and thus the advantages mentioned above can be attained. In particular, conduction need not be along a graphite network or skeleton where the graphite particles must be in mutual contact, and which is readily destroyed under mechanical and thermal stress, but it rather occurs along the ductile and aging-resistant polymer.

Both electroconductive polymerizates such as polystyrene, polyvinyl resins, polyacrylic acid derivatives and mixed polymerizates of these, and electroconductive polyamides and their derivatives, polyfluorinated hydrocarbons, epoxy resins and polyurethanes can be used as intrinsically electroconductive polymers. Polyamides, polymethyl methacrylates, epoxides, polyurethanes as well as polystyrene or their mixtures can preferably be used. Polyamides additionally exhibit good adhesive

properties, which are advantageous for the preparation of the resistance-heating element according to the invention. Some polymers, for instance polyacetylenes, are eliminated from uses according to the invention because of their low aging resistance due to reactivity with oxygen.

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The length of the polymer molecules used varies within wide ranges, depending on the type and structure of the polymer, but is preferably at least 500 and particularly preferably at least 4000 Å.

- 10 In one embodiment, the resistance layer has a support material. This support material on one hand can serve as carrier material for the intrinsically conductive polymer, on the other hand it functions as a spacer, particularly between the electrodes and the floating electrode. The support material in addition confers some rigidity on the resistance-heating element, so that this will be able to resist mechanical stress.
- 15 Moreover, when using a support material one can precisely adjust the layer thickness of the resistance layer. Glass spheres, glass fibers, rock wool, ceramics such as barium titanate or plastics can serve as support materials. A support material present as a tissue or mat, for instance of glass fibers, can be immersed into a mass consisting of the intrinsically electroconductive polymer, i.e., can be impregnated with the
- 20 intrinsically electroconductive polymer. The layer thickness then is determined by the thickness of the grid or mat. Methods such as scraping, spreading or known screen-printing methods can also be used.

- Preferably, the support material is a flat porous, electrically insulating material. With
- 25 such a material it can in addition be prevented that the heating current flows through the support material rather than through the polymer structure.

- The possibility of producing layers which across their surface deviate from the desired layer thickness with minimum tolerances, for instance 1 %, is of particular signifi-
- 30 cance, especially with the small layer thicknesses used according to the invention, since otherwise one would have to be afraid of a direct contact between contacted electrode and floating electrode. Fluctuations in layer thickness across the layer

surface can also influence the temperature generated, and lead to a nonuniform temperature distribution.

5 The support material has the further effect that the current cannot flow along the shortest path between the electrodes and the floating electrode but is deflected or split up at the filler material. Thus an optimum utilization of the energy supplied is achieved.

10 The object of the invention is explained in the following with the aid of the accompanying drawings.

It is shown:

15 in figure 1 a partial sectional view of one embodiment of the heating element according to the invention;

in figure 2 a schematic lateral view of an embodiment with several floating electrodes;

20 in figure 3 a diagrammatic sketch of the zones developing in an embodiment according to figure 2.

The heating element 1 has a thin resistance layer 2 and two flat electrodes 3 and 4 arranged side by side at a distance from each other and covering essentially all of the resistance layer. On the opposite side of the resistance layer 2 a floating electrode 5 is
25 arranged which covers the resistance layer over the full area formed by the electrodes 3 and 4 as well as by the gap between these electrodes. When the electrodes 3 and 4 are brought in contact with a source of current (not shown), the current will first spread within electrode 3, then flows through the resistance layer 2, essentially in a direction normal to its surface facing the floating electrode 5, is conducted further
30 within this electrode, flows through the resistance layer 2 to the electrode 4 and is drained from there. Depending on the contact arrangement at electrodes 3 and 4, the

current may also flow in the opposite direction. In the embodiment represented, the insulation between electrodes 3 and 4 is formed by an air gap.

In figure 2, a heating element is shown which has a thin resistance layer 2. On one side of the resistance layer 2, two flat electrodes 3 and 4 as well as several intermediate floating electrodes 5 are provided. Electrodes 3 and 4 and the floating electrodes 5 are at distances from each other and offset relative to the floating electrodes 5 arranged on the opposite side of the resistance layer 2. In this arrangement, the current applied to electrodes 3 and 4 flows through the resistance layer 2 and floating electrodes 5 in the direction indicated by arrows in the drawing. With this current flow, resistance layer 2 serves as a series arrangement of a number of electric resistances, which makes it possible to attain high power while in the individual sectors or zones of the resistance layer a low voltage prevails. Here, both the resistance residing in the thickness of the resistance layer 2 and the surface resistance in the gaps between the floating electrodes 5 or floating electrode 5 and the electrode 3 or 4 is utilized. The large distance in space between the contacted electrodes moreover offers the advantage that an immediate contact between them can be avoided.

Figure 3 shows a diagrammatic sketch which will be used to explain the electro-technical dimensions of an embodiment of the resistance-heating element according to the invention. Starting from the heating power per unit area of the full resistance-heating element which is desired in a particular case, one first determines the number of heating zones required across the width of the resistance-heating element from the ratio between the overall voltage to be applied to the contacted electrodes and the unique, maximum partial voltage applied to the individual partial zones which always are arranged in series. The length of the heating zone is designated as S, the width Z of the individual zones itself is calculated with the following formula:

$$Z = [B - n \cdot A/2 - 2 \cdot K]/n$$

where

B = total width of the flat heating element (mm)

A = distance between the floating electrodes or floating electrode and the electrode on one side of the resistance layer (mm)

5 K = width of the lateral band (mm)

n = number of individual heating zones arranged in series

10 Die width of the individual electrodes or floating electrodes which are arranged in alternation on either surface of the resistance layer can be found from the sum of two zone widths and the distance A between the electrodes arranged on one side of the resistance layer.

15 The heating power N_Z of an individual zone of the resistance-heating element can be found from:

$$N_Z = U_Z \cdot I_G = U_Z^2 \cdot L = U_Z^2 \cdot S \cdot Z / \rho \cdot D$$

20 where

U = the maximum permitted electric zone voltage applied to the partial resistance because of the electrical insulation (breakdown resistance) of the resistance-heating layer required in an individual application (V)

25 I = current, which because of the series arrangement is constant in all partial resistances, and equal to the total current (A)

L = electric conductance of the intrinsically conductive polymer resistance layer (S)

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ρ = specific resistance of the polymer layer ($\Omega \cdot \text{cm}$)

S = length of the electrode of the resistance-heating element (mm)

35 Z = width of the individual heating zones (mm)

D = thickness of the resistance layer (mm)

40 Both the electrodes and the floating electrode in the heating element according to the invention can for instance consist of metal foil or metal sheet. Moreover, the

electroconductive layer can be coated with black plastic on the side facing away from the resistance layer. With this additional layer, the heating element according to the invention can assume the function of a black body and generate a penetration effect of the radiation generated.

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In the heating element according to the invention, a multitude of electrodes can be provided on one side of the resistance layer. When providing a number of electrodes separated from each other by insulation, arranged next to each other and functioning as electrode pairs to which a voltage can be applied, one can achieve a heating-up of the heating element zone by zone.

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It is also within the scope of the invention to realize the insulation between the electrodes with an insulating material introduced into the gap between the electrodes. Conventional dielectrics and particularly so plastics can be used as the insulating material.

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In the event that no voltage should be present at the surface of the heating element that is facing the body to be heated, one can laminate the resistance layer or the floating electrode with polyester, PTFE, polyimide and other foils. The use of these conventional insulating materials and of a simple form such as a foil becomes possible in the heating element according to the invention because the floating electrode is free of contact terminals and hence has a smooth surface.

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The resistance layer can have a structure in which different resistive materials with different specific electric resistances are present in the form of layers.

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This embodiment has the advantage that by suitable selection of the materials in the resistance layer, the side of the resistance layer from which heat is to be transferred to the body to be heated, can have higher temperatures, while it is not necessary that different heating currents are separately conducted, for instance with heating wires, in individual layers of the resistance layer. This is achieved when the specific electric resistance of the polymer employed is selected so as to increase from the layer that is

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adjacent to the electrodes, in a direction to the side facing the body or object to be heated.

Because of the resistance layer and contact arrangement employed, the resistance-heating element according to the invention can be operated, both with low voltages of for instance 24 V and with very high voltages of for instance 240, 400 and up to 1000 V.

With the resistance-heating element according to the invention, heating powers per unit area in excess of 10 kW/m^2 and preferably in excess of 30 kW/m^2 can be achieved. With the heating element, heating powers of up to 60 kW/m^2 can be achieved. Such a heating power of up to 60 kW/m^2 can even be achieved with a layer thickness of the resistance layer of 1 mm. The time-dependent drop in heating power can be smaller than 0.01 % per year when a voltage of 240 V is continuously applied.

The temperature that can be achieved with the resistance-heating element is limited by the thermal properties of the polymer selected, but can be higher than 240°C and up to 500°C . The polymer should in particular be so selected that even at the temperatures to be achieved, conduction continues to be electronic.

The heating element can have the most diverse shapes when using the resistance layer that is employed according to the invention. The resistance-heating element can have the shape of tape with a length larger than the width where the electrodes are strips which extend over the full length of the tape and in the direction of the width of the resistance-heating element are arranged side by side. Square shapes are also possible with the heating element according to the invention.

The resistance-heating element can for instance be mounted on the inside or outside of a pipe. Here the unilateral contact arrangement of the heating element is a particular advantage, since heat transfer from the resistance-heating element to the body to be heated, such as a pipe, is not hindered by contact terminals. The electrical insulation

between the body to be heated and the resistance-heating element is also simplified by the lack of contact points on the electroconductive layer.

5 Within the scope of the invention, the intrinsically electroconductive polymer can also be selected so that over some range of temperatures it has a negative temperature coefficient of electric resistance. Thus, the temperature coefficient can become positive above a particular temperature, e.g., 80 °C.

10 The further objective of the invention is reached by a heatable pipe, where an inner pipe is coated on its outside at least in part, directly or via an interlayer, with a thin resistance layer containing an intrinsically electroconductive polymer, and where on the outer surface of the resistance layer at least two flat electrodes which cover the resistance layer at least in part are arranged at a distance from each other.

15 In the pipe according to the invention, the resistance layer contains an intrinsically electroconductive polymer. These polymers which, according to the invention, are used in the resistance layer have a constitution such that the current flows along the polymer molecules. Owing to the polymer structure, the heating current is conducted through the resistance layer along the polymers. Because of the electric resistance of
20 the polymers, heat is generated which can be transferred to the inner pipe to be heated. Here the heating current cannot follow the shortest pathway between the two electrodes but follows the structure of the polymer arrangement. Thus, the length of the current path is predetermined by the polymers, so that even in the instance of small layer thicknesses, relatively high voltages can be applied without causing a
25 voltage breakdown. Even in the instance of high currents such as making currents, one must not be afraid of a burn-out. Moreover, the distribution of the current in the first electrode and its subsequent conduction along the polymer structure in the resistance layer leads to a homogeneous temperature distribution within the resistance layer. This distribution arises immediately after applying voltage to the electrodes.

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Because of the polymers employed according to the invention, the pipe can be operated even at high voltages, for instance line voltage. As the attainable heating

power increases with the square of operating voltage, the resistance-heating element according to the invention can yield high heating power and hence high temperatures. According to the invention, the current density is minimized because a relatively long current path is provided along the electroconductive polymers or because at least two
5 zones electrically in series which contain the intrinsically electroconductive polymer used according to the invention are created.

Moreover, the electroconductive polymers used according to the invention exhibit long-term stability. This stability is explained above all by the fact that the polymers
10 are ductile, so that a rupture of the polymer chains and thus interruption of the current path will not occur when the temperature is raised. The polymer chains are unharmed even after repeated temperature fluctuation. In conventional resistance-heating elements, to the contrary, where conductivity is created, for instance, by carbon black skeletons, such a thermal expansion would lead to interruption of the current path and
15 hence to overheating. This would lead to a strong oxidation and to burn-out of the resistance layer. The intrinsically electroconductive polymer used according to the invention is not subject to such aging phenomena.

The intrinsically conductive polymers used according to the invention resist aging
20 even in reactive environments such as air oxygen. Moreover, current conduction through the resistive mass used according to the invention is of the electronic conduction type. Hence even an autodestruction of the resistance layer by electrolysis reactions caused by electric currents will not occur in the resistance-heating element according to the invention. In the resistance-heating element according to the
25 invention, time-dependent drops in heating power per unit area are very small and approximately zero, even at temperatures as high as 500 °C for instance, and at heating powers per unit area as high as 50 kW/m² for instance.

This long-term stability or aging resistance is of particular significance for the pipe
30 according to the invention, since heatable pipes are used for instance underground or in other places not readily accessible, so that frequent repairs are undesirable if not impossible.

Due to the use of intrinsically electroconductive polymers, the resistance layer as a whole which is used according to the invention presents a homogeneous structure that permits a heating that is uniform across the entire layer.

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According to the invention, contact to the pipe is provided by two electrodes which preferably consist of a material of high electric conductivity and are arranged on one side of the resistance layer. This type of contact arrangement makes it possible to use the mode of operation of the intrinsically conductive polymers used according to the invention in a particularly advantageous way. The applied current first spreads within the first electrode, then crosses the thickness of the resistance layer along the polymer structure, and finally is conducted to the second contacted electrode. Therefore, the current path is additionally extended over that present in a structure where the resistance layer is sandwiched between the two electrodes. Because of this flow of the current, the thickness of the resistance layer can be kept small.

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The pipe according to the invention has the further advantage of being versatile in its applications. The electrodes are provided with contacts on one side of the resistance layer. This faces away from the inner pipe and hence is readily accessible for making connections. The opposite side of the resistance layer facing the inner pipe therefore is free of contact terminals, and hence can be of flat shape. This flat surface permits a direct application of the resistance layer to the inner pipe. An ideal heat transfer to the inner pipe becomes possible since the contact area between the resistance-heating element and the inner pipe to be heated is not disrupted by contact terminals.

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With this structure according to the invention, pipes are easy to heat. The inner pipe can be provided with the resistance layer and the electrodes, and if required with the interlayer, already at the place of manufacture and incorporated into the pipeline on the spot in this finished state.

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In an embodiment of the pipe according to the invention, this pipe has an interlayer made of a material having a high electric conductivity between the inner pipe and the resistance layer.

- 5 Here the interlayer serves as floating electrode. In the spirit of the invention, an electrode is called floating when it is not connected to the source of current. It can have an insulation preventing electric contact with a source of current.

10 This floating electrode supports the flow of current through the resistance layer. In this embodiment the current spreads within the first electrode, crosses the thickness of the resistance layer to reach the floating electrode on the opposite side, is conducted further within this electrode, and finally flows through the thickness of the resistance layer to the other electrode that is found on the side of the resistance layer facing away from the pipe. The interlayer can be insulated from the inner pipe by foils. The
15 insulation of the interlayer, which is not provided with contacts, can occur with known foils consisting of polyimide, polyester and silicone rubber.

In this embodiment of the heatable pipe, the current flows through the thickness of the resistance layer, essentially in a direction normal to its surface. Essentially two zones
20 develop within the resistance layer. Within the first zone, the current flows essentially vertically from the first contacted electrode to the floating electrode, while within the second zone, it flows essentially vertically from the floating electrode to the second contacted electrode. Thus, a series arrangement of several resistances is attained by this arrangement. This effect implies that the partial voltage prevailing in the
25 individual zones is smaller than the applied voltage. Thus, in this embodiment of the invention the voltage prevailing in the individual zones is half of the applied voltage. Because of the low voltage prevailing in the resistance layer, safety risks can be reliably avoided with the pipe according to the invention, and possible applications thus are manifold. Thus, the pipe according to the invention can be employed in wet
30 areas or moist ground or find applications where people must touch the pipe.

Moreover, the gap provided between the contacted electrodes acts as an additional resistance arranged in parallel. With air as the insulator in this gap, the resistance will be determined by the mutual distance of the electrodes and thus by the surface resistance of the resistance layer. The distance is preferably larger than the thickness
5 of the resistance layer, for instance twice the thickness of the resistance layer.

The electrodes and the floating electrode preferably have a good thermal conductivity. This can exceed 200 W/m·K, preferably 250 W/m·K. Local overheating can rapidly be neutralized by this good thermal conductivity in the electrodes. An overheating is
10 thus possible only in the direction of layer thickness, but has no negative effects because of the small layer thickness that can be realized in the pipe according to the invention. It is a further advantage of the pipe that even a local temperature increase provoked from inside, e.g., from the inner pipe to be heated, can be balanced in an ideal way by the resistance-heating element. Such an increase in temperature can
15 occur for instance in pipes only partly filled, since in zones that are filled with air, less heat is transferred from the pipe to the air.

The heatable pipe has the further advantage that the resistance layer arranged on the inner pipe can withstand even high stresses without giving rise to a local temperature
20 rise. As a rule, the mechanical stress acting on a laid pipe, particularly one laid underground, is directed radially. This is the direction of current flow in the resistance layer of the resistance-heating element. Such a stress will therefore not lead to an increase in resistance in places where pressure is exerted, contrary to resistance-heating elements where the current would flow in a direction normal to the
25 compressive load.

In a further embodiment of the heatable pipe according to the invention, the resistance layer is arranged directly on the inner pipe, which consists of an electroconductive material.

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In this embodiment, the flow of current from one electrode to the next is directed via the resistive mass and the inner pipe. In view of the low voltages prevailing in the

resistance layer of the pipe according to the invention, the inner pipe which here functions as a floating electrode can be adduced without safety risks as a current conductor. In this embodiment, the heat generated can at the same time readily be transferred to the medium present in the pipe. In this version, the inner pipe can be
5 covered with the resistance layer over its entire periphery, and the electrodes can cover this layer essentially completely. However, the gap between the electrodes that must be provided for electrical reasons is present as well in this embodiment.

According to a further embodiment, the resistance layer and the electrodes arranged
10 on this layer extend longitudinally in an axial direction, and the electrodes are arranged on the resistance layer at distances from each other in the direction of the circumference.

15 In view of the longitudinal extension of the resistance layer and the electrodes, a certain length of pipe can be heated while the current supply is needed only in a single point of each of the two electrodes.

In a preferred embodiment, the resistance layer covers only part of the periphery of
20 the inner pipe and extends longitudinally in an axial direction. Preferably, the length of the resistance layer and electrodes corresponds to that of the pipe.

In this embodiment, heat can be transferred to the pipe within a definite region where the resistance layer or, if present, the interlayer is applied to the inner pipe. In the case
25 of pipes with an inner pipe having good thermal conductivity, the heat transferred from the resistance layer is distributed over the full periphery of the inner pipe and thus can heat the medium present in the pipe to the full extent. This structure thus provides good heating of the medium while requiring little engineering effort. However, this embodiment is only possible when the heatable pipe has a structure
30 according to the invention. Only such a structure makes it possible to achieve high power per unit area while avoiding any damage to the resistance layer during

extended operation and under the influence of reactive substances such as water or air oxygen.

The resistance layer preferably covers a part of the periphery which, when the pipe
5 has been laid, is situated on the lower side of the pipe. This guarantees that even in a pipe not completely filled, the medium to be heated is in contact with this partial zone and thus is heated reliably and rapidly.

In the pipe according to the invention, the electrodes and the interlayer preferably
10 consist of a material with a specific electric resistance of less than 10^{-4} Ω -cm, preferably of less than 10^{-5} Ω -cm. Suitable materials are aluminum and copper, for instance. This is of particular significance in the pipe according to the invention. As a rule, pipes are used to build pipelines. It will be advantageous when the electrical resistance of the electrodes is low, since in such a pipeline consisting of pipes
15 according to the invention, the resistance layer and the electrodes are very long. With such an electrode material one can avoid a voltage drop across the electrode surface which would lead to an overall decrease in power. Moreover, the conductivity guarantees a rapid distribution of the current within the electrode, which permits a rapid and uniform heating-up of essentially the entire resistance layer and thus the
20 length of the pipe while it is not necessary to apply voltage to the electrodes in several points along their length or width. It may then not be necessary to arrange power supply lines along the pipe. Such pipes can have a length of up to 1 m. According to the invention, such an arrangement with multiple contact points is only selected in embodiments where the pipe is longer. The limiting length above which a multiple
25 contact arrangement will be meaningful depends, both on the electrode material selected and on the place of the contacts. Thus, multiple contact points may be unnecessary even for lengths more important than those mentioned above when the electrodes are accessible in the midpoint of their length, and a contact can be provided at that point.

30 The length of the pipe that can be operated with single contacts also depends on the thickness of the electrodes selected. According to one embodiment, the electrodes and

the interlayer each have a thickness in the range of 50 to 150 μm , preferably 75 to 100 μm each. These small layer thicknesses are also advantageous in that the heat produced by the resistance-heating element can readily be transferred from the interlayer to the pipe. Moreover, thin electrodes are more flexible, so that a detachment of the electrodes from the resistance layer and thus an interruption of the electrical contact during thermal expansion of the resistance layer will be avoided.

In pipelines of great length, a multiple contact arrangement may yet be necessary. With the pipe according to the invention, however, this is readily provided. The electrodes are only provided with contact terminals from the outside, so that these are readily accessible. Thus, a power line extending along the pipe and connecting the electrodes at intervals to the voltage source can be provided along the pipeline. This makes it possible to operate long pipes according to the invention.

According to the invention, the resistance layer is thin. Its thickness has a lower limit that merely depends on the breakdown voltage, and is preferably 0.1 to 2 mm, preferably 1 mm. A small layer thickness of the resistance layer offers the advantage of enabling a short heat-up time, rapid heat transfer and high heating power per unit area. However, such a layer thickness is only possible with the intrinsically conductive polymer and contact arrangement used. On one hand, the current path within the resistance layer is predetermined by the polymers used according to the invention, and can be sufficiently long to prevent voltage breakdown, even when the layer thicknesses are small. On the other hand, the unilateral contact arrangement permits subdivision of the resistance layer into zones with lower voltage, which additionally reduces the risk of breakdown.

The advantages of the pipe according to the invention are further enhanced when the resistance layer has a positive temperature coefficient (PTC) of its electric resistance. This leads to an effect of automatic regulation with respect to the highest attainable temperature. Overheating of the pipe and reactions in the pipe caused by this overheating can be avoided by this effect. This effect occurs, since the flow of current through the resistive mass is adjusted as a function of temperature because of the PTC

of the resistance layer. The current becomes lower the higher the temperature, until at a particular thermal equilibrium it has become immeasurably small. A local overheating and melting of the resistive mass can therefore be prevented reliably. This effect is of particular significance in the present invention. If for instance the pipe is only half-filled with a liquid medium, heat is more readily withdrawn from this region of the pipe than from the region of the pipe where the pipe is air-filled. A conventional resistance-heating element would heat up and perhaps melt because of deficient heat withdrawal. In the heatable pipe according to the invention, this melting is avoided by the effect of automatic regulation.

Selecting a PTC material for the resistance layer also implies, therefore, that as a result, the entire resistance layer is heated to essentially the same temperature. This enables uniform heat transfer, which can be essential for particular applications of the pipe, for instance when heat-sensitive media are conveyed through the pipe.

According to the invention, the resistance layer can be metallized on its surfaces facing the electrodes and the interlayer. By metallization, metal adheres to the surface of the resistance layer and thus improves the flow of current between the electrodes or the floating electrode and the resistance layer. Moreover, in this embodiment the heat transfer from the resistance layer to the floating electrode and hence to the inner pipe to be heated is also improved. The surface can be metallized by spraying of metal. Such a metallization is possible only with the material of the resistance layer that is used according to the invention. A costly metallization step, for instance by metal electroplating, hence is superfluous and considerably reduces the manufacturing costs.

The intrinsically electroconductive polymer is preferably produced by doping of a polymer. The doping can be a metal or semimetal doping. In these polymers the defect carrier is chemically bound to the polymer chain and generates a defect. The doping atoms and the matrix molecule form a so-called charge-transfer complex. During doping, electrons from filled bands of the polymer are transferred to the dopant. On account of the electronic holes thus generated, the polymer takes on semiconductor-like electrical properties. In this embodiment, a metal or semimetal

atom is incorporated into or attached to the polymer structure by chemical reaction in such a way that free charges are generated which enable the flow of current along the polymer structure. The free charges are present in the form of free electrons or holes. In this way an electronic conductor arises.

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Preferably, for its doping the polymer was mixed with such an amount of dopant that the ratio of atoms of the dopant to the number of polymer molecules is at least 1:1, preferably between 2:1 and 10:1. With this ratio it is achieved that essentially all polymer molecules are doped with at least one atom of the dopant. The conductance
10 of the polymers and hence that of the resistance layer as well as the temperature coefficient of resistance of the resistance layer can be adjusted by selecting the ratio.

The intrinsically electroconductive polymer used according to the invention can be employed as material for the resistance layer in the resistance-heating element
15 according to the invention, even without graphite addition, but according to a further embodiment, the resistance layer may additionally contain graphite particles. These particles can contribute to the conductivity of the complete resistance layer, are preferably not in mutual contact, and in particular do not form a reticular or skeletal structure. The graphite particles are not solidly bound into the polymer structure but
20 are freely mobile. When a graphite particle is in contact with two polymer molecules, the current can jump via the graphite from one chain to the next. The conductivity of the resistance layer can be further raised in this way. On account of their free mobility in the resistance layer, the graphite particles can also move to the surface of this layer and bring about an improvement of its contact with the electrodes or the interlayer or
25 with the inner pipe.

The graphite particles are preferably present in an amount of at most 20 vol.%, and particularly preferably in an amount of at most 5 vol.% relative to the total volume of the resistance layer, and have a mean diameter of at most 0.1 μm . With this small
30 amount of graphite and the small diameter, formation of a graphite network which would lead to current conduction through these networks can be avoided. It is thus guaranteed that the current essentially continues to flow by electronic conduction via

the polymer molecules, and thus the advantages mentioned above can be attained. In particular, conduction need not be along a graphite network or skeleton where the graphite particles must be in mutual contact, and which is readily destroyed under mechanical and thermal stress, but it rather occurs along the ductile and aging-resistant polymer.

Both electroconductive polymerizates such as polystyrene, polyvinyl resins, polyacrylic acid derivatives and mixed polymerizates of these, and electroconductive polyamides and their derivatives, polyfluorinated hydrocarbons, epoxy resins and polyurethanes can be used as intrinsically electroconductive polymers. Polyamides, polymethyl methacrylates, epoxides, polyurethanes as well as polystyrene or their mixtures can preferably be used. Polyamides additionally exhibit good adhesive properties, which are advantageous for the production of the pipe according to the invention, since this facilitates application to the inner pipe or to the interlayer. Some polymers, for instance polyacetylenes, are eliminated from uses according to the invention because of their low aging resistance due to reactivity with oxygen.

The length of the polymer molecules used varies within wide ranges, depending on the type and structure of the polymer, but is preferably at least 500 and particularly preferably at least 4000 Å.

In one embodiment, the resistance layer has a support material. This support material on one hand can serve as carrier material for the intrinsically conductive polymer, on the other hand it functions as a spacer, particularly between the electrodes and the interlayer or the electroconductive inner pipe. The support material in addition confers some rigidity on the resistance-heating element, so that this will be able to resist mechanical stress. Moreover, when using a support material one can precisely adjust the layer thickness of the resistance layer. Glass spheres, glass fibers, rock wool, ceramics such as barium titanate or plastics can serve as support materials. A support material present as a tissue or mat, for instance of glass fibers, can be immersed into a mass consisting of the intrinsically electroconductive polymer, i.e., can be impregnated with the intrinsically electroconductive polymer. The layer thickness then is

determined by the thickness of the grid or mat. Methods such as scraping, spreading or known screen-printing methods can also be used.

Preferably, the support material is a flat porous, electrically insulating material. With
5 such a material it can in addition be prevented that the heating current flows through the support material rather than through the polymer structure.

The possibility of producing layers which across their surface deviate from the desired layer thickness with minimum tolerances, for instance 1 %, is of particular signi-
10 ficance, especially with the small layer thicknesses used according to the invention, since otherwise one would have to be afraid of a direct contact between contacted electrode and floating electrode. Fluctuations in layer thickness across the layer surface can also influence the temperature generated, and lead to a nonuniform temperature distribution.

15 The support material has the further effect that the current cannot flow along the shortest path between the electrodes and the floating electrode but is deflected or split up at the filler material. Thus an optimum utilization of the energy supplied is achieved.

20 The further object of the invention is explained in the following with the aid of the accompanying drawings.

It is shown:

25 in figure 4 a sectional view of an embodiment of a pipe according to the invention without thermal insulation layer, and

in figure 5 a sectional view of an embodiment of a pipe according to the invention
30 with thermal insulation layer.

In figure 4 the heatable pipe 10 consists of an inner pipe 11 and of a resistance layer 12 arranged on it which covers the inner pipe 11 over its entire periphery. Two electrodes 13 and 14 which are flat and are separated from each other by an electrical insulation 16 are arranged on the resistance layer 12. When a current is applied from a source of current (not shown) to the electrodes 13, 14, it flows from the one electrode 13 through the resistance layer 12 to the inner pipe 11. In this embodiment, the inner pipe 11 preferably consists of an electroconductive material. The current is conducted within the wall of the inner pipe 11 and flows through the resistance layer 12 to the second electrode 14. The entire resistance layer 12 is heated up by this heating current and can transfer this heat via the inner pipe 11 to the interior of the pipe.

In Figure 5, a resistance-heating element 12, 13, 14, 15, 16 is applied to part of the periphery of the inner pipe 11. This element has an electroconductive layer 15 facing the inner pipe 11. This layer 15 is flat and covered by a resistance layer 12 on the side facing away from the inner pipe 11. On the resistance layer 12, two electrodes 13 and 14 are arranged at a distance from each other. Across the region not in contact with the resistance-heating element, the inner pipe 11 is covered by a thermal insulation layer 17. Around this thermal insulation layer 17, an insulating shell 18 is arranged which encloses, both the thermal insulation layer 17 and the resistance-heating element 12, 13, 14, 15, 16. The pipe further has power supply installations 19. The power supply installations 19 are connected with supply lines 19a running parallel to the axis of the inner pipe 11 through the insulating shell 18. These supply lines 19a extend over the entire length of the pipe and at the end of the pipe can be connected to a source of current (not shown) or linked with the supply lines 19a of the following pipe. Materials which will enhance the heat transfer can be provided between the inner pipe 11 and the electroconductive layer 15 facing the inner pipe 11. These materials can be thermally conducting pastes, pads with thermally conducting material, silicone rubber, etc. However, in this embodiment the resistance-heating element 12, 13, 14, 15, 16 can also be adapted to the curvature of the inner pipe 11, which guarantees an immediate heat transfer.

In the embodiments shown, electrodes 13, 14 extend in the longitudinal direction of the pipe and peripherally are arranged side by side. It is also within the scope of the invention that electrodes 13 and 14 are so arranged on the resistance layer 12 that they extend peripherally but are arranged side by side in an axial direction.

5

With the supply lines running parallel to the pipe axis, several pieces of pipe each having the structure according to the invention can be arranged in series while the power supplies of the individual resistance-heating elements of the pipe pieces are arranged in parallel. The supply lines are protected against damage or contact, for instance with water, by the insulating shell.

10

The thermal insulation layer has the purpose to avoid heat losses by radiation in a direction away from the inner pipe and direct the heat generated by the resistance-heating element predominantly in the direction of the inner pipe. The thermal insulation layer can consist of insulating materials and in addition, where necessary, of a reflecting layer.

15

It is possible, too, to apply the thermal insulation layer all around the pipe while the resistance layer as well as the flat electrodes and the interlayer are arranged within a longitudinal groove of the thermal insulation layer that faces the inner pipe. Here the thermal insulation layer prevents heat transfer across the remaining part of the inner pipe's periphery that is not covered by the resistance layer or interlayer. By arranging the resistance-heating element within the thermal insulation layer, good contact between this layer and the inner pipe over the remaining part of the periphery is guaranteed. The embodiments shown in figures 4 and 5 can additionally be provided with clamping devices. Optionally, these clamping devices can be mounted externally on each of the heatable pipes represented, for instance with adhesive tape or locking rings or, in the embodiment shown in figure 5, they can also be arranged directly on the outer surface of the resistance-heating element. In this latter case the devices can consist of foam rubber. Particularly in the case of large pipes, inflatable or foamable chambers can be provided on the side of the resistance-heating element facing away

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from the inner pipe. The clamping devices guarantee a constant clamping pressure and hence a good heat transfer from the resistance-heating element to the inner pipe.

5 A resistance-heating element such as shown in figure 2 can also be used. In the pipe according to the invention, this resistance-heating element is used in such a way that the side of the resistance-heating element on which the contacted electrodes are arranged faces away from the inner pipe. Preferably, the electrodes and the floating electrodes are arranged in such a way that they are at a distance from each other on the periphery of the pipe and extend in an axial direction. This gives rise to the
10 formation of several peripheral zones, with a voltage prevailing in each zone that is lower than the voltage applied. The electrical dimensions are established according to the diagrammatical sketch 3 and associated mathematical relations when such a resistance-heating element is used.

15 In the heatable pipe according to the invention, the inner pipe can consist for instance of metal or plastic, and particularly of polycarbonate. The resistance-heating element can comprise an interlayer between the inner pipe and the resistance layer when a material without electrical conductivity is selected for the inner pipe. However, it is also within the scope of the invention to provide a resistance-heating element for such
20 an inner pipe which only comprises the electrodes and the resistance layer. In this embodiment the heating current is conducted from the one electrode to the other electrode through the resistive mass of the resistance layer, i.e., through the electroconductive polymer. This current path is feasible with the pipe according to the invention since the structure of the polymers secures sufficiently large current flow
25 through the resistive mass and thus a sufficient heat production.

It is within the scope of the invention to lay the supply lines which are connected via the power supply installations to the electrodes of the resistance-heating element on the outer surface of the insulating shell.

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Conventional dielectrics and particularly plastics can serve as insulating pieces between the electrodes contacted with current.

The terminals for current supply to the heating element are provided as needed, by insulated braids having any desired length or by permanently glued contact terminals using known systems for the connections.

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It is also within the scope of the invention to use a material for the resistance layer that has a negative temperature coefficient of electric resistance.

10 A very small making current is required when the temperature coefficient of electric resistance is negative. The material of the resistance layer can moreover be so selected that at a particular temperature, for instance 80 °C, the resistive mass used according to the invention reverts so that above this temperature the temperature coefficient of the electric resistance becomes positive.

15 The resistance layer can have a structure in which different resistive materials with different specific electric resistances are present in the form of layers.

This embodiment has the advantage that by suitable selection of the materials in the resistance layer, the side of the resistance layer from which heat is to be transferred to
20 the body to be heated, can have higher temperatures, while it is not necessary that different heating currents are separately conducted, for instance with heating wires, in individual layers of the resistance layer. This is achieved when the specific electric resistance of the polymer employed is selected so as to increase from the layer that is adjacent to the electrodes, in a direction to the side facing the pipe to be heated.

25

Because of the resistance layer and contact arrangement employed, the pipe according to the invention can be operated, both with low voltages of for instance 24 V and with very high voltages of for instance 240, 400 and up to 1000 V.

30 With the pipe according to the invention, heating powers per unit area in excess of 10 kW/m² and preferably in excess of 30 kW/m² can be achieved. With the heating element, heating powers of up to 60 kW/m² can be achieved. Such a heating power of

up to 60 kW/m^2 can even be achieved with a layer thickness of the resistance layer of 1 mm. The time-dependent drop in heating power can be smaller than 0.01 % per year when a voltage of 240 V is continuously applied.

- 5 The temperature that can be achieved with the pipe is limited by the thermal properties of the polymer selected, but can be higher than 240 °C and up to 500 °C.

The pipe according to the invention can be a piece of pipe of any desired length. Such pieces of pipe can optionally be linked with further pipes according to the invention or
10 with conventional, not heatable pipe pieces to form a pipeline. It is thus possible to only heat those segments of the pipeline where a particular temperature must be set, for instance in order to avoid freezing. The costs of a pipeline can be optimized when using this selective heating. Pipes according to the invention can be made in lengths of 10 cm and also of up to 2 m.

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It is also possible to provide just part of the length of a pipe with the structure according to the invention. Further, one or several resistance-heating elements can be arranged within the thermal insulation layer of the pipe according to the invention. These can extend in a radial or axial direction. Here the resistance-heating elements
20 can be arranged in a peripheral distribution, for instance in several longitudinal grooves of an insulation layer.

A cathodic protecting voltage can be generated at the inner pipe which will prevent corrosion of the pipe when direct current is applied to the electrodes of the heating
25 element and the inner pipe is made of an electroconductive material.

The pipe can also be structured in such a way that the inner pipe is formed by a conventional pipe and that this pipe is surrounded by two half-shells where at least one of the half-shells comprises a resistance-heating element. The half-shells are
30 preferably made of insulating material such as glass fibers or plastic foam.

Using a pipe according to the invention, pipelines for instance can be laid even in regions where one must be afraid of a freezing of pipes.

5 The further objective of the invention is reached by a heatable transportation device for media comprising a container receiving the medium, where the container on its outer surface is covered at least in part, either directly or via an interlayer, with a thin resistance layer containing an intrinsically electroconductive polymer and where at least two flat electrodes which cover the resistance layer at least in part are arranged at a distance from each other on the outer surface of the resistance layer.

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With the transportation device according to the invention, the container can be heated simply and reliably.

15 In the transportation device according to the invention, the resistance layer contains an intrinsically electroconductive polymer. These polymers which, according to the invention, are used in the resistance layer have a constitution such that the current flows along the polymer molecules. Owing to the polymer structure, the heating current is conducted through the resistance layer along the polymers. Because of the electric resistance of the polymers, heat is generated which can be transferred to the container to be heated. Here the heating current cannot follow the shortest pathway between the two electrodes but follows the structure of the polymer arrangement. Thus, the length of the current path is predetermined by the polymers, so that even in the instance of small layer thicknesses, relatively high voltages can be applied without causing a voltage breakdown. Even in the instance of high currents such as making
20 currents, one must not be afraid of a burn-out. Moreover, the distribution of the current in the first electrode and its subsequent conduction along the polymer structure in the resistance layer leads to a homogeneous temperature distribution within the resistance layer. This distribution arises immediately after applying voltage to the electrodes.

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Because of the polymers employed according to the invention, the transportation device can be operated even at high voltages, for instance line voltage. As the

attainable heating power increases with the square of operating voltage, it is possible with the transportation device according to the invention to achieve high heating powers and hence high temperatures. According to the invention, the current density is minimized because a relatively long current path is provided along the electroconductive polymers or because at least two zones electrically in series which
5 contain the intrinsically electroconductive polymer used according to the invention are created.

Moreover, the electroconductive polymers used according to the invention exhibit
10 long-term stability. This stability is explained above all by the fact that the polymers are ductile, so that a rupture of the polymer chains and thus interruption of the current path will not occur when the temperature is raised. The polymer chains are unharmed even after repeated temperature fluctuation. In conventional resistance-heating elements used for heatable transportation devices, to the contrary, where conductivity
15 is created, for instance, by carbon black skeletons, such a thermal expansion would lead to interruption of the current path and hence to overheating. This would lead to a strong oxidation and to burn-out of the resistance layer. The intrinsically electroconductive polymer used according to the invention is not subject to such aging phenomena.

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The intrinsically conductive polymers used according to the invention resist aging even in reactive environments such as air oxygen. Thus, even an autodestruction of the resistance layer by electrolysis reactions caused by electric currents will not occur in the transportation device according to the invention. In the resistance-heating
25 element according to the invention, time-dependent drops in heating power per unit area are very small and approximately zero, even at temperatures as high as 500 °C for instance, and at heating powers per unit area as high as 50 kW/m² for instance.

Due to the use of intrinsically electroconductive polymers, the resistance layer as a
30 whole which is used according to the invention presents a homogeneous structure that permits a heating that is uniform across the entire layer.

According to the invention, contact to the transportation device is provided by two electrodes which preferably consist of a material of high electric conductivity and are arranged on one side of the resistance layer. This type of contact arrangement makes it possible to use the mode of operation of the intrinsically conductive polymers used according to the invention in a particularly advantageous way. The applied current first spreads within the first electrode, then crosses the thickness of the resistance layer along the polymer structure, and finally is conducted to the second contacted electrode. Therefore, the current path is additionally extended over that present in a structure where the resistance layer is sandwiched between the two electrodes. Because of this flow of the current, the thickness of the resistance layer can be kept small.

The transportation device according to the invention has the further advantage of being versatile in its applications. The electrodes are provided with contacts on one side of the resistance layer. This is the side facing away from the container, and hence readily accessible for making connections. The opposite side of the resistance layer facing the container is free of contact terminals, and hence can be of flat shape. Such a flat surface permits a direct application of the resistance layer to the container. An ideal heat transfer becomes possible since the contact area between the resistance-layer and the container is not disrupted by contact terminals.

In an embodiment of the container according to the invention, this container has an interlayer made of a material having a high electric conductivity between the container and the resistance layer.

The interlayer serves as floating electrode here. In the spirit of the invention, an electrode is called floating when it is not connected to the source of current. It can have an insulation preventing electric contact with a source of current.

This floating electrode supports the flow of current through the resistance layer. In this embodiment the current spreads within the first electrode, crosses the thickness of the resistance layer to reach the floating electrode on the opposite side, is conducted

further within this electrode, and finally flows through the thickness of the resistance layer to the other electrode that is arranged on the side of the resistance layer facing away from the container. The interlayer can be insulated from the container by foils. The insulation of the interlayer, which is not provided with contacts, can occur with
5 known foils consisting of polyimide, polyester and silicone rubber.

In this embodiment of the heatable transportation device, the current flows through the thickness of the resistance layer, essentially in a direction normal to its surface. Essentially two zones develop within the resistance layer. Within the first zone, the
10 current flows essentially vertically from the first contacted electrode to the floating electrode, while within the second zone, it flows essentially vertically from the floating electrode to the second contacted electrode. Thus, a series arrangement of several resistances is attained by this arrangement. This effect implies that the partial voltage prevailing in the individual zones is smaller than the applied voltage. Thus, in
15 this embodiment of the invention the voltage prevailing in the individual zones is half of the applied voltage. Because of the low voltage prevailing in the resistance layer, safety risks can be reliably avoided with the transportation device according to the invention, and possible applications thus are manifold. The transportation device according to the invention can thus also be used in applications in which people must
20 touch the container. In the transport of media, the device according to the invention is exposed to the atmospheric conditions. Thus, the device can come in contact with water, particularly in the rain or snow. However, a safety risk will not arise by this contact because of the extremely low voltage prevailing in the resistance layer of the device according to the invention. It is possible, moreover, to operate the device
25 according to the invention with a conventional power source such as a battery. This is readily mounted on the railroad car or truck. In the latter instance the device according to the invention can even be powered by the truck's battery, which represents an additional design simplification.

30 Moreover, the gap provided between the contacted electrodes acts as an additional resistance arranged in parallel. With air as the insulator in this gap, the resistance will be determined by the mutual distance of the electrodes and thus by the surface

resistance of the resistance layer. The distance is preferably larger than the thickness of the resistance layer, for instance twice the thickness of the resistance layer.

The electrodes and the floating electrode preferably have a good thermal conductivity.

5 This can exceed 200 W/m·K, preferably 250 W/m·K. Local overheating can rapidly be neutralized by this good thermal conductivity in the electrodes. An overheating is thus possible only in the direction of layer thickness, but has no negative effects because of the small layer thickness that can be realized in the transportation device according to the invention. It is a further advantage of the transportation device that
10 even a local temperature increase provoked from outside, e.g., from the environment by solar irradiation, can be balanced in an ideal way by the resistance-heating element. Such a temperature rise can also occur from the inside, for instance with containers only partly filled, since heat transfer from the container to the air is lower in the air-filled zones.

15

The heatable transportation device has the further advantage that the resistance layer arranged on the container can withstand even high stresses without giving rise to a local temperature rise. As a rule, the mechanical stress acting on a container is directed radially. This is the direction of current flow in the resistance layer of the
20 resistance-heating element. Such a stress will therefore not lead to an increase in resistance in places where pressure is exerted, contrary to resistance-heating elements where the current would flow in a direction normal to the compressive load.

In a further embodiment of the heatable transportation device according to the
25 invention, the resistance layer is arranged directly on the container, which consists of an electroconductive material.

In this embodiment, the flow of current from one electrode to the next is directed via the resistive mass and the container. In view of the low voltages prevailing in the
30 resistance layer of the transportation device according to the invention, the container which here functions as a floating electrode can be adduced without safety risks as a current conductor. In this embodiment, the heat generated can at the same time readily

be transferred to the medium present in the container. In this version, the container can be covered with the resistance layer over its entire periphery, and the electrodes can cover this layer essentially completely. However, the gap between the electrodes that must be provided for electrical reasons is present as well in this embodiment.

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According to a further embodiment, the resistance layer and the electrodes arranged on this layer extend longitudinally in an axial direction, and the electrodes are arranged on the resistance layer at distances from each other in the direction of the circumference.

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In view of the longitudinal extension of the resistance-heating element formed by the resistance layer and the electrodes and, where present, the interlayer, it is possible to merely heat a particular region of the container, while power supply is only needed at one point of each of the two electrodes.

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In a preferred embodiment, the resistance layer covers only part of the periphery of the container and extends longitudinally in an axial direction. Preferably, the length of the resistance layer and electrodes corresponds to that of the container.

20 In this embodiment, heat can be transferred to the container within a definite region where the heating element formed by the resistance layer and the electrodes and, if present, the interlayer is applied to the container. In transportation devices where the container has a good thermal conductivity, the heat generated by the resistance-heating element is distributed over the full periphery of the container and thus can
25 heat the medium present in the container to the full extent. This structure thus provides good heating of the medium while requiring little engineering effort. However, this embodiment is only possible with a structure of the heatable transportation device according to the invention. Only such a structure makes it possible to achieve high power per unit area while avoiding any damage to the
30 resistance layer during extended operation and under the influence of reactive substances such as water or air oxygen.

The resistance layer preferably covers a part of the periphery which is situated on the lower side of the container when this is mounted. This guarantees that even in a container not completely filled, the medium to be heated is in contact with this partial zone and thus is heated reliably and rapidly.

5

In the transportation device according to the invention, the electrodes and the interlayer preferably consist of a material with a specific electric resistance of less than $10^{-4} \Omega\cdot\text{cm}$, preferably of less than $10^{-5} \Omega\cdot\text{cm}$. Suitable materials are aluminum and copper, for instance. This is of particular significance in the transportation device according to the invention. Manufactured containers for transportation devices as a rule are very long. Since in such a transportation device the resistance-heating element is very long, it will be advantageous to have electrodes with low electric resistance. With such an electrode material one can avoid a voltage drop across the electrode surface which would lead to an overall decrease in power. Moreover, the conductivity guarantees a rapid distribution of the current within the electrode, which permits a rapid and uniform heating-up of essentially the entire resistance layer and thus the length of the container while it is not necessary to apply voltage to the electrodes in several points along their length or width. It may then not be necessary to arrange power supply lines along the container. Such containers can have a length of up to 1 m. According to the invention, such an arrangement with multiple contact points is only selected in embodiments where the container is very long. The limiting length above which a multiple contact arrangement will be meaningful depends, both on the electrode material selected and on the place of the contacts. Thus, multiple contact points may be unnecessary even for lengths more important than those mentioned above when the electrodes are accessible in the midpoint of their length, and a contact can be provided at that point.

The length of the transportation device that can be operated with single contacts also depends on the thickness of the electrodes selected. According to one embodiment, the electrodes and the interlayer each have a thickness of 50 to 150 μm , preferably 75 to 100 μm each. These small layer thicknesses are also advantageous in that the heat produced by the resistance layer can readily be transferred from the interlayer to the

container. Moreover, thin electrodes are more flexible, so that a detachment of the electrodes from the resistance layer and thus an interruption of the electrical contact during thermal expansion of the resistance layer will be avoided.

- 5 In containers of great length, a multiple contact arrangement may yet be necessary. With the transportation device according to the invention, however, this is readily provided. The electrodes are only provided with contact terminals from the outside, so that these are readily accessible. Thus, a power line extending along the container and connecting the electrodes at intervals to the voltage source can be provided for a
10 container. This makes it possible to operate transportation devices according to the invention having any desirable length.

- According to the invention, the resistance layer is thin. Its thickness has a lower limit that merely depends on the breakdown voltage, and is preferably 0.1 to 2 mm,
15 preferably 1 mm. A small layer thickness of the resistance layer offers the advantage of enabling a short heat-up time, rapid heat transfer and high heating power per unit area. However, such a layer thickness is only possible with the intrinsically conductive polymer and contact arrangement used. On one hand, the current path within the resistance layer is predetermined by the polymers used according to the
20 invention, and can be sufficiently long to prevent voltage breakdown, even when the layer thicknesses are small. On the other hand, the unilateral contact arrangement of the resistance-heating element permits subdivision of the resistance layer into zones of lower voltage, which additionally reduces the risk of breakdown.

- 25 The advantages of the transportation device according to the invention are further enhanced when the resistance layer has a positive temperature coefficient (PTC) of its electric resistance. This leads to an effect of automatic regulation with respect to the highest attainable temperature. With this effect, overheating of the container and reactions in the container caused by this overheating can be avoided. This effect
30 occurs, since the flow of current through the resistive mass is adjusted as a function of temperature because of the PTC of the resistance layer. The current becomes lower the higher the temperature, until at a particular thermal equilibrium it has become

- immeasurably small. A local overheating and melting of the resistive mass can therefore be prevented reliably. This is particularly important in the present invention. If for instance the container is only half-filled with a liquid medium, then heat in this region of the container is more readily dissipated than in the region where air is present in the container. On account of a lack of heat dissipation, a conventional resistance-heating element would heat up and might melt. In the heatable container according to the invention, to the contrary, this melting is avoided by the effect of automatic regulation.
- 10 Selecting a PTC material for the resistance layer also implies, therefore, that as a result, the entire resistance layer is heated to essentially the same temperature. This enables uniform heat transfer, which can be essential for particular applications of the container, for instance when transporting heat-sensitive media in the container.
- 15 According to the invention, the resistance layer can be metallized on its surfaces facing the electrodes and the interlayer. By metallization, metal adheres to the surface of the resistance layer and thus improves the flow of current between the electrodes or the floating electrode and the resistance layer. Moreover, in this embodiment the heat transfer from the resistance layer to the floating electrode and hence to the container is also improved. The surface can be metallized by spraying of metal. Such a metallization is possible only with the material of the resistance layer that is used according to the invention. A costly metallization step, for instance by metal electroplating, hence is superfluous and considerably reduces the manufacturing costs.
- 25 The intrinsically electroconductive polymer is preferably produced by doping of a polymer. The doping can be a metal or semimetal doping. In these polymers the defect carrier is chemically bound to the polymer chain and generates a defect. The doping atoms and the matrix molecule form a so-called charge-transfer complex. During doping, electrons from filled bands of the polymer are transferred to the dopant. On account of the electronic holes thus generated, the polymer takes on semiconductor-like electrical properties. In this embodiment, a metal or semimetal atom is incorporated into or attached to the polymer structure by chemical reaction in
- 30

such a way that free charges are generated which enable the flow of current along the polymer structure. The free charges are present in the form of free electrons or holes. In this way an electronic conductor arises.

- 5 Preferably, for its doping the polymer was mixed with such an amount of dopant that the ratio of atoms of the dopant to the number of polymer molecules is at least 1:1, preferably between 2:1 and 10:1. With this ratio it is achieved that essentially all polymer molecules are doped with at least one atom of the dopant. The conductance of the polymers and hence that of the resistance layer as well as the temperature
10 coefficient of resistance of the resistance layer can be adjusted by selecting the ratio.

The intrinsically electroconductive polymer used according to the invention can be employed as material for the resistance layer in the resistance-heating element according to the invention, even without graphite addition, but according to a further
15 embodiment, the resistance layer may additionally contain graphite particles. These particles can contribute to the conductivity of the complete resistance layer, are preferably not in mutual contact, and in particular do not form a reticular or skeletal structure. The graphite particles are not solidly bound into the polymer structure but are freely mobile. When a graphite particle is in contact with two polymer molecules,
20 the current can jump via the graphite from one chain to the next. The conductivity of the resistance layer can be further raised in this way. On account of their free mobility in the resistance layer, the graphite particles can also move to the surface of this layer and bring about an improvement of its contact with the electrodes or interlayer or with the container.

25 The graphite particles are preferably present in an amount of at most 20 vol.%, and particularly preferably in an amount of at most 5 vol.% relative to the total volume of the resistance layer, and have a mean diameter of at most 0.1 μm . With this small amount of graphite and the small diameter, formation of a graphite network which
30 would lead to current conduction through these networks can be avoided. It is thus guaranteed that the current essentially continues to flow by electronic conduction via the polymer molecules, and thus the advantages mentioned above can be attained. In

particular, conduction need not be along a graphite network or skeleton where the graphite particles must be in mutual contact, and which is readily destroyed under mechanical and thermal stress, but it rather occurs along the ductile and aging-resistant polymer.

5

Both electroconductive polymerizates such as polystyrene, polyvinyl resins, polyacrylic acid derivatives and mixed polymerizates of these, and electroconductive polyamides and their derivatives, polyfluorinated hydrocarbons, epoxy resins and polyurethanes can be used as intrinsically electroconductive polymers. Polyamides, polymethyl methacrylates, epoxides, polyurethanes as well as polystyrene or their mixtures can preferably be used. Polyamides additionally exhibit good adhesive properties, which are advantageous for the production of the transportation device according to the invention, since this facilitates application to the container or interlayer. Some polymers, for instance polyacetylenes, are eliminated from uses according to the invention because of their low aging resistance due to reactivity with oxygen.

15

The length of the polymer molecules used varies within wide ranges, depending on the type and structure of the polymer, but is preferably at least 500 and particularly preferably at least 4000 Å.

20

In one embodiment, the resistance layer has a support material. This support material on one hand can serve as carrier material for the intrinsically conductive polymer, on the other hand it functions as a spacer, particularly between the electrodes and the interlayer or container. The support material in addition confers some rigidity on the resistance-heating element, so that this will be able to resist mechanical stress. Moreover, when using a support material one can precisely adjust the layer thickness of the resistance layer. Glass spheres, glass fibers, rock wool, ceramics such as barium titanate or plastics can serve as support materials. A support material present as a tissue or mat, for instance of glass fibers, can be immersed into a mass consisting of the intrinsically electroconductive polymer, i.e., can be impregnated with the intrinsically electroconductive polymer. The layer thickness then is determined by the

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thickness of the grid or mat. Methods such as scraping, spreading or known screen-printing methods can also be used.

Preferably, the support material is a flat porous, electrically insulating material. With
5 such a material it can in addition be prevented that the heating current flows through the support material rather than through the polymer structure.

The possibility of producing layers which across their surface deviate from the desired layer thickness with minimum tolerances, for instance 1 %, is of particular
10 significance, especially with the small layer thicknesses used according to the invention, since otherwise one would have to be afraid of a direct contact between contacted electrode and the interlayer or container. Fluctuations in layer thickness across the layer surface can also influence the temperature generated, and lead to a nonuniform temperature distribution.

15 The support material has the further effect that the current cannot flow along the shortest path between the electrodes and the interlayer or inner pipe but is deflected or split up at the filler material. Thus an optimum utilization of the energy supplied is achieved.

20 The transportation device according to the invention is explained in the following with the aid of the accompanying drawings.

It is shown:

25 in figure 6 a sectional view of an embodiment of a device according to the invention without thermal insulation layer;

in figure 7 a sectional view of an embodiment of a device according to the invention
30 with a resistance-heating element incorporated into the thermal insulation layer;

in figure 8 a perspective view of the embodiment of a device according to the invention shown in figure 7.

In figure 6 the device 20 consists of a tubular container 21 and a resistance layer 22
5 arranged on this container which over the entire periphery covers the container 21. Two electrodes 23 and 24 which are flat and are separated from each other by an electrical insulation 26 are arranged on the resistance layer 22. When current is applied from a source of current (not shown) to electrodes 23, 24 it will flow from the one electrode 23 through the resistance layer 22 to the container 21. In this embodi-
10 ment the container 21 preferably consists of an electroconductive material. The current is conducted along the wall of container 21 and flows through the resistance layer 22 to the second electrode 24. The entire resistance layer 22 is heated up by this heating current and can transfer this heat via container 21 to the interior of the container.

15

In figure 7 a resistance-heating element is applied to part of the periphery of a tubular container 21. This element has an electroconductive layer 25 facing the container 21. This layer 25 is flat and covered with a resistance layer 22 on the side facing away from the container 21. Two electrodes 23 and 24 are arranged at a distance from each
20 other on the resistance layer 22. Over the region not in contact with the resistance-heating element, the container 21 is covered by a thermal insulation layer 27. An insulating shell 28 which surrounds, both the thermal insulation layer 27 and the resistance-heating element 22, 23, 24, 25, 26 is arranged around the thermal insulation layer 27. The device further contains power supply installations 29. The power supply
25 installations 29 are connected with supply lines 29a which run parallel to the axis of the tubular container 21 through the insulating shell 28. These supply lines 29a extend over the entire length of the insulating shell 28 and at its end can be connected to a source of current (not represented) or linked with the supply lines 29a of a further insulating shell 28 with resistance-heating element and thermal insulation layer 27
30 arranged on the container 21. Between the container 21 and the electroconductive layer 25 facing the container 21, materials which will improve the heat transfer can be provided. These can be thermally conducting pastes, pads with thermally conducting

material, silicone rubber, and others. In this embodiment, the resistance-heating element 22, 23, 24, 25, 26 can also be adapted to the curvature of container 21, which guarantees an immediate heat transfer.

- 5 In the embodiments shown, the electrodes 23, 24 extend in the longitudinal direction of the container 21 and peripherally are arranged side by side. It is within the scope of the invention, too, to arrange electrodes 23, 24 in such a way on the resistance layer 22 that they extend in the peripheral direction of the container 21 and are arranged side by side in an axial direction.

10

The supply lines running parallel to the container axis make it possible to arrange several insulating shells with a resistance-heating element and a thermal insulation layer in series on the container and arrange the power supplies of the individual resistance-heating elements in parallel. The supply lines are protected against damage
15 or contact with water for instance by the insulating shell.

- The resistance-heating element is preferably arranged within the insulating shell in such a way that it adjoins the container from below. This position of the heating element has the advantage that heat can readily be transferred from the heating
20 element, even to a container which is filled to a small extent.

- In figure 8, the container 21 is surrounded by an insulating shell 28 over the largest part of its length. The resistance-heating element 22, 23, 24, 25, 26 as well as the supply lines 29a and the power supply installations 29 are arranged within the
25 insulating shell 28. The resistance-heating element extends over large part of the length of insulating shell 28 and terminates within the insulating shell 28. The supply lines 29a protrude at the end of the insulating shell and can be connected to a source of current (not represented). The fastening devices with which the transportation device according to the invention can be arranged on a railroad car or truck are shown
30 schematically in figure 8. These fastening devices preferably are arranged in such a way that neither the insulating shell nor the resistance-heating element is exposed to compressive stresses when the container rests on the fastening devices.

A resistance-heating element as shown in figure 2 can also be used. In the transportation device according to the invention, the resistance-heating element is used in such a way that the side of the resistance-heating element on which the contacted electrodes are arranged is facing in a direction away from the container.
5 When using such a resistance-heating element, the electrical dimensions are determined in accordance with the diagrammatic sketch 3 and associated mathematical relations. In the device according to the invention, this resistance-heating element is used in such a way that the side of the resistance-heating element on which the electrodes are arranged is facing away from the container. In the case of a cylindrical container, the electrodes and floating electrodes are preferably arranged in such a way that they extend in the direction of the container axis and are peripherally spaced on the container. Several zones within which voltages prevails that are lower than the applied voltage are thus formed peripherally.

15

The thermal insulation layer has the purpose to avoid heat losses by radiation in a direction away from the container and direct the heat generated by the resistance-heating element predominantly in the direction of the inner pipe. The thermal insulation layer can consist of insulating materials and in addition, where necessary,
20 of a reflecting layer.

It is possible, too, that the entire container is surrounded by the thermal insulation layer while the resistance layer as well as the flat electrodes and the interlayer are arranged within a longitudinal groove of the thermal insulation layer that faces the container. In this embodiment, heat can be transferred to the container across a
25 specific region where the heating element is adjoining the container. At the same time, heat losses across the remaining region of the container are prevented by the thermal insulation layer. By arranging the resistance-heating element within the thermal insulation layer, good contact between this layer and the container across the remaining region is guaranteed. Such an embodiment can also be used for devices
30 where the container has a good thermal conductivity. With these containers, the heat generated by the resistance-heating element is distributed over the entire surface area

of the container wall and can thus additionally heat the medium present in the container. With this structure one thus achieves, on one hand a heating of the medium by infrared radiation coming from the resistance-heating element, and on the other hand a direct heating by the resistance-heating element and the container wall.

5

The embodiments shown can additionally be provided with clamping devices. Optionally, these clamping devices can be mounted externally on each of the devices according to the invention that are represented, for instance with adhesive tape or locking rings, or in the embodiments shown in figures 7 and 8, they can also be arranged directly on the outer surface of the resistance-heating element. In this latter case the devices can consist of foam rubber. In particular, inflatable or foamable chambers can be provided on the side of the resistance-heating element facing away from the container. The clamping devices guarantee a constant clamping pressure and hence a good heat transfer from the resistance-heating element to the container.

15

Preferably, the container is tubular. However, it can also have other shapes, for instance rectangular.

In the device according to the invention, the container can consist for instance of metal or plastic, and preferably of polycarbonate. The resistance-heating element can comprise an interlayer between the container and the resistance layer when a material without electrical conductivity is selected for the container. However, it is also within the scope of the invention to provide a resistance-heating element for such a container which only comprises the electrodes and the resistance layer. In this embodiment the heating current is conducted from the one electrode to the other electrode through the resistive mass of the resistance layer, i.e., through the electroconductive polymer. This current path is feasible with the device according to the invention since the structure of the polymers secures sufficiently large current flow through the resistive mass and thus a sufficient heat production.

30

It is within the scope of the invention to lay the supply lines which are connected via the power supply installations to the electrodes of the resistance-heating element on the outer surface of the insulating shell.

- 5 Conventional dielectrics and particularly plastics can serve as insulating pieces between the electrodes contacted with current.

The terminals for current supply to the heating element are provided as needed, by insulated braids having any desired length or by permanently glued contact terminals
10 using known systems for the connections.

It is also within the scope of the invention to use a material for the resistance layer that has a negative temperature coefficient of electric resistance.

- 15 A very small making current is required when the temperature coefficient of electric resistance is negative. The material of the resistance layer can moreover be so selected that at a particular temperature, for instance 80 °C, the resistive mass used according to the invention reverts so that above this temperature the temperature coefficient of the electric resistance becomes positive.

20

The resistance layer can have a structure in which different resistive materials with different specific electric resistances are present in the form of layers.

- This embodiment has the advantage that by suitable selection of the materials in the
25 resistance layer, the side of the resistance layer from which heat is to be transferred to the container can have higher temperatures, while it is not necessary that different heating currents are separately conducted, for instance with heating wires, in individual layers of the resistance layer. This is achieved when the specific electric resistance of the polymer employed is selected so as to increase from the layer that is
30 adjacent to the electrodes, in a direction to the side facing the container to be heated.

Because of the resistance layer and contact arrangement employed, the transportation device according to the invention can be operated, both with low voltages of for instance 24 V and with very high voltages of for instance 240, 400 and up to 1000 V.

- 5 With the transportation device according to the invention, heating powers per unit area in excess of 10 kW/m^2 and preferably in excess of 30 kW/m^2 can be achieved. With the container, heating powers of up to 60 kW/m^2 can be achieved. Such a heating power of up to 60 kW/m^2 can even be achieved with a layer thickness of the resistance layer of 1 mm. The time-dependent drop in heating power can be smaller
10 than 0.01 % per year when a voltage of 240 V is continuously applied.

The temperature that can be achieved with the transportation device is limited by the thermal properties of the polymer selected, but can be higher than 240 °C and up to 500 °C.

15

- It is also possible to provide just part of the length of the container with the insulating shell with resistance-heating element and thermal insulation layer. Further, depending on the particular application, the size of the resistance-heating element can be selected so that one or several resistance-heating elements can be arranged within the thermal
20 insulation layer. In the case of a tubular container, these can extend in a radial or axial direction. Here the resistance-heating elements can for instance be arranged in several longitudinal grooves of an insulation layer.

- The device can also be structured in such a way that the inner pipe is formed by a
25 conventional container and that this is surrounded by two half-shells where at least one of the half-shells comprises a resistance-heating element. The half-shells are preferably made of insulating material such as glass fibers or plastic foam.

- The further objective of the invention is reached by a heat roller comprising a roller
30 shell and at least one flat resistance-heating element arranged on the inner surface of the roller shell, while the resistance-heating element consists of at least two flat

electrodes and a thin resistance layer containing an intrinsically electroconductive polymer.

In the roller according to the invention, the resistance layer contains an intrinsically electroconductive polymer. These polymers which, according to the invention, are
5 used in the resistance layer have a constitution such that the current flows along the polymer molecules. Owing to the polymer structure, the heating current is conducted through the resistance layer along the polymers. Because of the electric resistance of the polymers, heat is generated which can be transferred to the roller shell to be
10 heated. Here the heating current cannot follow the shortest pathway between the two electrodes but follows the structure of the polymer arrangement. Thus, the length of the current path is predetermined by the polymers, so that even in the instance of small layer thicknesses, relatively high voltages can be applied without causing a voltage breakdown. Even in the instance of high currents such as making currents, one
15 must not be afraid of a burn-out.

Moreover, the distribution of the current in the first electrode and its subsequent conduction along the polymer structure in the resistance layer leads to a homogeneous temperature distribution within the resistance layer. This distribution arises
20 immediately after applying voltage to the electrodes.

Because of the polymers employed according to the invention, the roller can be operated even at high voltages, for instance line voltage. As the attainable heating power increases with the square of operating voltage, the heat roller according to the
25 invention can yield high heating power and hence high temperatures. According to the invention, the current density is minimized because a relatively long current path is provided along the electroconductive polymers.

Moreover, the electroconductive polymers used according to the invention exhibit
30 long-term stability. This stability is explained above all by the fact that the polymers are ductile, so that a rupture of the polymer chains and thus interruption of the current path will not occur when the temperature is raised. The polymer chains are unharmed

even after repeated temperature fluctuation. In conventional resistance-heating elements used for heat rollers, to the contrary, where conductivity is created, for instance, by carbon black skeletons, such a thermal expansion would lead to interruption of the current path and hence to overheating. This would lead to a strong oxidation and to burn-out of the resistance layer. The intrinsically electroconductive polymer used according to the invention is not subject to such aging phenomena.

The intrinsically conductive polymers used according to the invention resist aging even in reactive environments such as air oxygen. Thus, even an autodestruction of the resistance layer by electrolysis reactions caused by electric currents will not occur in the heat roller according to the invention. The time-dependent drops in heating power per unit area achieved in the resistance layer are very small and approximately zero, even at temperatures as high as 500 °C for instance, and at heating powers per unit area as high as 50 kW/m² for instance.

In view of the use of intrinsically electroconductive polymers, the resistance layer according to the invention has an overall homogeneous structure permitting a uniform heating across the entire layer.

By selecting an intrinsically electroconductive polymer as the material of the resistance layer, one guarantees on one hand sufficient flexibility of the heating element, so that this element is readily applied to the inner surface of a roller, on the other hand heat is generated uniformly over a large area. In operation, the resistance-heating element is protected against mechanical stress when it is provided on the inner surface of the roller shell.

The resistance-heating element with electroconductive polymer can moreover serve as "black body". This body can emit radiation of all wavelengths. The wavelength of the emitted radiation shifts more and more toward the infrared as the temperature decreases. The infrared radiations of the roller can act upon the goods to be heated when the roller is made of a material that transmits these radiations, such as glass or

plastic. In the resistance layer itself, high temperatures are not required because of the effect of penetration.

In one embodiment, the resistance layer is arranged between the electrodes which are
5 connected to a source of current and cover the resistance layer at least in part. In this
embodiment the roller shell itself may for instance serve as one of the electrodes. The
resistance layer is then applied in predetermined thickness, directly to the inner
surface of the roller. A counterelectrode will then be arranged on the side of the
resistance layer that is facing away from the roller shell. The heating current applied
10 to the electrode and to the roller shell serving as an electrode flows through the
resistive mass, essentially across its thickness. This structure guarantees a good heat
transfer to the goods to be heated, because the roller shell is in direct contact with the
resistance layer.

15 However, in this embodiment it is also possible that on the inner surface of the roller
shell a flat electrode is arranged which on its side facing away from the roller shell is
covered with a resistance layer. The other electrode is then arranged on top of this
resistance layer. Here the heating current flows between the two electrodes, and the
roller surface can remain voltage-free. This embodiment is advantageous primarily in
20 applications where a direct contact between the heat roller and for instance the user of
the device can occur.

According to a further embodiment, the at least two flat electrodes are arranged at a
distance from each other on the side of the resistance layer facing away from the roller
25 shell.

According to the invention, the roller is contacted by two electrodes arranged on one
side of the resistance layer. In this contact arrangement the operating mode of the
intrinsically conductive polymers used according to the invention can be exploited
30 particularly advantageously. The applied current first spreads within the first
electrode, then flows along the polymer structure through the thickness of the
resistance layer, essentially in a direction normal to the surface, and finally is

conducted to the second contacted electrode. The current path thus is additionally extended relative to that in a structure where the resistance layer is sandwiched between the two electrodes. Because of this current path, the thickness of the resistance layer can be kept particularly small.

5

This embodiment of the roller according to the invention has the further advantage that the electrodes are provided with contacts on one side of the resistance layer. This side faces away from the roller shell and hence is readily accessible for providing contact terminals. The opposite side of the resistance layer which faces the roller shell
10 is free of contact terminals, and hence can be of flat shape. Such a flat surface permits a direct application of the resistance layer to the roller shell. An ideal heat transfer to the roller shell of up to 98 % becomes possible since the contact area between the resistance-heating layer and the body to be heated is not disrupted by contact terminals. In addition, a uniform heat transfer can reliably occur from the resistance-
15 heating element to the roller shell and thus to the goods to be heated.

On the side of the resistance layer facing away from the electrodes, an interlayer made of a material with high electric conductivity can be provided between the resistance layer and the roller shell. This interlayer serves as a floating electrode. However, it is
20 also within the scope of the invention when in this embodiment the resistance layer is applied directly to the roller shell. An electrical insulation of the interlayer or resistance layer from the roller shell can also be realized by simple means, for instance a foil.

25 In this embodiment of the heat roller, the current flows through the thickness of the resistance layer, essentially in a direction normal to its surface. Essentially two zones develop within the resistance layer. Within the first zone, the current flows essentially vertically from the first contacted electrode to the floating electrode, while within the second zone, it flows essentially vertically from the floating electrode to the second
30 contacted electrode. Thus, a series arrangement of several resistances is attained by this arrangement. This effect implies that the partial voltage prevailing in the individual zones is smaller than the applied voltage. Thus, in this embodiment of the

invention the voltage prevailing in the individual zones is half of the applied voltage. Because of the low voltage prevailing in the resistance layer, safety risks can reliably be avoided with the heat roller according to the invention.

5 Moreover, the gap provided between the contacted electrodes acts as an additional resistance arranged in parallel. With air as the insulator in this gap, the resistance will be determined by the mutual distance of the electrodes and thus by the surface resistance of the resistance layer. The distance is preferably larger than the thickness of the resistance layer, for instance twice the thickness of the resistance layer.

10

The electrodes and the floating electrode preferably have a good thermal conductivity. This can exceed 200 W/m·K, preferably 250 W/m·K. Local overheating can rapidly be neutralized by this good thermal conductivity in the electrodes. An overheating is thus possible only in the direction of layer thickness, but has no negative effects
15 because of the small layer thickness that can be realized in the heat roller according to the invention. It is a further advantage of the heat roller that even a local temperature increase provoked from outside, e.g., from the goods to be heated, can be balanced in an ideal way by the resistance-heating element. Such a temperature rise can also be produced from the inside, for instance when an accumulation of heat occurs in the
20 roller. For this reason a thermal insulating material can be provided inside the roller.

The heatable heat roller has the further advantage that the resistance layer arranged on the roller shell can withstand even high stresses without giving rise to a local temperature rise. As a rule, the mechanical stress acting on the roller shell is directed
25 radially. This is the direction of current flow in the resistance layer of the resistance-heating element. Such a stress will therefore not lead to an increase in resistance in places where pressure is exerted, contrary to resistance-heating elements where the current would flow in a direction normal to the compressive load.

30 According to the invention, electrodes which are applied to the side of the resistance layer facing away from the roller shell can essentially extend over the full periphery and can be spaced in an axial direction.

This arrangement is advantageous, since in a heat roller which is in rotary motion when in service, a current supply can occur from the two roller ends.

- 5 According to a further embodiment of the invention, the resistance layer can have a structure in which layers of different resistive materials with different specific electric resistances are present. In this embodiment the side of the resistance layer facing the interior of the roller can consist of a material having a low resistance. On top of this layer, further layers of materials having specific resistances increasing from one layer
10 to the next are applied. In this arrangement, the side facing the roller shell has the highest specific resistance of the resistance layer, so that this surface heats up more strongly, since here the largest voltage drop occurs.

- In the roller according to the invention, the electrodes and the interlayer preferably
15 consist of a material with a specific electric resistance of less than $10^{-4} \Omega\cdot\text{cm}$, preferably of less than $10^{-5} \Omega\cdot\text{cm}$. Suitable materials are aluminum or copper, for instance. This is of particular importance in the roller according to the invention. Heat rollers which are used for instance as copying roller or foil coating roller must heat up quickly, and have a uniform temperature over their entire length. With an electrode
20 material having such a specific resistance, a voltage drop across the surface of the electrode which would lead to an overall performance drop and to temperatures which differ across the surface can be avoided. The conductivity also guarantees a rapid spread of the current within the electrode, which permits a rapid, uniform heating-up of essentially all of the resistance layer and hence of the length of the roller while it is
25 not necessary that voltage is applied at a number of points along the length or width of the electrodes.

- The heat-up rate and the temperature generated across the roller surface further depend on the thickness of the electrodes selected. According to one embodiment, the
30 electrodes and the interlayer have a thickness in the range of 50 to 150 μm , preferably 75 to 100 μm each. These small layer thicknesses are also advantageous in that the heat produced by the resistance layer is readily transferred from the interlayer to the

roller shell. Moreover, thin electrodes are more flexible, so that a detachment of the electrodes from the resistance layer and thus an interruption of the electrical contact during thermal expansion of the resistance layer will be avoided.

- 5 According to the invention, the resistance layer is thin. Its thickness has a lower limit that merely depends on the breakdown voltage, and is preferably 0.1 to 2 mm, preferably 1 mm. A small layer thickness of the resistance layer offers the advantage of enabling a short heat-up time, rapid heat transfer and high heating power per unit area. However, such a layer thickness is only possible with the intrinsically
10 conductive polymer used, and can be further improved by the kind of contact arrangement used. On one hand, the current path within the resistance layer is predetermined by the polymers used according to the invention, and can be sufficiently long to prevent voltage breakdown, even when the layer thicknesses are small. On the other hand, the unilateral contact arrangement of the resistance-heating
15 element permits subdivision of the resistance layer into zones of lower voltage, which additionally reduces the risk of breakdown.

- The advantages of the roller according to the invention are further enhanced when the resistance layer has a positive temperature coefficient (PTC) of its electric resistance.
20 This leads to an effect of automatic regulation with respect to the highest attainable temperature. With this effect, local overheating of the roller shell can be prevented. This effect occurs, since the flow of current through the resistive mass is adjusted as a function of temperature because of the PTC of the resistance layer. The current becomes lower the higher the temperature, until at a particular thermal equilibrium it
25 has become immeasurably small. A local overheating and melting of the resistive mass can therefore be prevented reliably. This effect is of particular importance in the present invention.

- Selecting a PTC material for the resistance layer also implies, therefore, that as a
30 result, the entire resistance layer is heated to essentially the same temperature. This enables uniform heat transfer, which can be essential for particular applications of the

roller, since otherwise in some spots for instance the foil to be applied by the roller will not adhere to the substrate, since it was not sufficiently heated.

According to the invention, the resistance layer can be metallized on its surfaces
5 facing the electrodes and the interlayer. By metallization, metal adheres to the surface of the resistance layer and thus improves the flow of current between the electrodes or the floating electrode and the resistance layer. Moreover, in this embodiment the heat transfer from the resistance layer to the floating electrode and hence to the roller shell is also improved. The surface can be metallized by spraying of metal. Such a metall-
10 ization is possible only with the material of the resistance layer that is used according to the invention. A costly metallization step, for instance by metal electroplating, hence is superfluous and considerably reduces the manufacturing costs.

The intrinsically electroconductive polymer is preferably produced by doping of a
15 polymer. The doping can be a metal or semimetal doping. In these polymers the defect carrier is chemically bound to the polymer chain and generates a defect. The doping atoms and the matrix molecule form a so-called charge-transfer complex. During doping, electrons from filled bands of the polymer are transferred to the dopant. On account of the electronic holes thus generated, the polymer takes on
20 semiconductor-like electrical properties. In this embodiment, a metal or semimetal atom is incorporated into or attached to the polymer structure by chemical reaction in such a way that free charges are generated which enable the flow of current along the polymer structure. The free charges are present in the form of free electrons or holes. In this way an electronic conductor arises.

25

Preferably, for its doping the polymer was mixed with such an amount of dopant that the ratio of atoms of the dopant to the number of polymer molecules is at least 1:1, preferably between 2:1 and 10:1. With this ratio it is achieved that essentially all polymer molecules are doped with at least one atom of the dopant. The conductance
30 of the polymers and hence that of the resistance layer as well as the temperature coefficient of resistance of the resistance layer can be adjusted by selecting the ratio.

The intrinsically electroconductive polymer used according to the invention can be employed as material for the resistance layer in the roller according to the invention, even without graphite addition, but according to a further embodiment, the resistance layer may additionally contain graphite particles. These particles can contribute to the conductivity of the complete resistance layer, are preferably not in mutual contact, and in particular do not form a reticular or skeletal structure. The graphite particles are not solidly bound into the polymer structure but are freely mobile. When a graphite particle is in contact with two polymer molecules, the current can jump via the graphite from one chain to the next. The conductivity of the resistance layer can be further raised in this way. On account of their free mobility in the resistance layer, the graphite particles can also move to the surface of this layer and bring about an improvement of its contact with the electrodes or interlayer or with the roller shell.

The graphite particles are preferably present in an amount of at most 20 vol.%, and particularly preferably in an amount of at most 5 vol.% relative to the total volume of the resistance layer, and have a mean diameter of at most 0.1 μm . With this small amount of graphite and the small diameter, formation of a graphite network which would lead to current conduction through these networks can be avoided. It is thus guaranteed that the current essentially continues to flow by electronic conduction via the polymer molecules, and thus the advantages mentioned above can be attained. In particular, conduction need not be along a graphite network or skeleton where the graphite particles must be in mutual contact, and which is readily destroyed under mechanical and thermal stress, but it rather occurs along the ductile and aging-resistant polymer.

Both electroconductive polymerizates such as polystyrene, polyvinyl resins, polyacrylic acid derivatives and mixed polymerizates of these, and electroconductive polyamides and their derivatives, polyfluorinated hydrocarbons, epoxy resins and polyurethanes can be used as intrinsically electroconductive polymers. Polyamides, polymethyl methacrylates, epoxides, polyurethanes as well as polystyrene or their mixtures can preferably be used. Polyamides additionally exhibit good adhesive properties, which are advantageous for the production of the roller according to the

invention, since this facilitates application to the roller shell or interlayer. Some polymers, for instance polyacetylenes, are eliminated from uses according to the invention because of their low aging resistance due to reactivity with oxygen.

- 5 The length of the polymer molecules used varies within wide ranges, depending on the type and structure of the polymer, but is preferably at least 500 and particularly preferably at least 4000 Å.

10 In one embodiment, the resistance layer has a support material. This support material on one hand can serve as carrier material for the intrinsically conductive polymer, on the other hand it functions as a spacer, particularly between the electrodes and the interlayer or roller shell. The support material in addition confers some rigidity on the resistance-heating element, so that this will be able to resist mechanical stress. Such a stress can for instance be generated by clamping devices such as locking rings used to
15 clamp the heating element to the roller shell. Moreover, when using a support material one can precisely adjust the layer thickness of the resistance layer. Glass spheres, glass fibers, rock wool, ceramics such as barium titanate or plastics can serve as support materials. A support material present as a tissue or mat, for instance of glass fibers, can be immersed into a mass consisting of the intrinsically electroconductive
20 polymer, i.e., can be impregnated with the intrinsically electroconductive polymer. The layer thickness then is determined by the thickness of the grid or mat. Methods such as scraping, spreading or known screen-printing methods can also be used.

25 Preferably, the support material is a flat porous, electrically insulating material. With such a material it can in addition be prevented that the heating current flows through the support material rather than through the polymer structure.

The possibility of producing layers which across their surface deviate from the desired layer thickness with minimum tolerances, for instance 1 %, is of particular
30 significance, especially with the small layer thicknesses used according to the invention, since otherwise one would have to be afraid of a direct contact between contacted electrode and floating electrode. Fluctuations in layer thickness across the

layer surface can also influence the temperature generated, and lead to a nonuniform temperature distribution.

5 The support material has the further effect that the current cannot flow along the shortest path between the electrodes and the floating electrode but is deflected or split up at the filler material. Thus an optimum utilization of the energy supplied is achieved.

10 The roller according to the invention is explained in the following with the aid of the accompanying drawings.

It is shown:

15 in figure 9 an embodiment of the heat roller according to the invention having a resistance layer sandwiched between the electrodes;

in figure 10 a longitudinal section of a heat roller according to the invention with two electrodes arranged side by side on one side of the resistance layer.

20 In figure 9, a heat roller 30 is shown where the inner surface of the roller shell 31 is covered by a flat electrode 33. The resistance layer 32 is arranged on this electrode 33 and has a further electrode 34 on the side facing away from the electrode 33. In the interior of the roller, a thermal insulating material 37 is arranged which completely fills the interior of the heat roller and adjoins the inner electrode 34. In the
25 embodiment represented, the electrodes 33 and 34 are connected to a source of current (not shown). The current flowing through the resistance layer 32 heats this layer and thus leads to a heating of the roller shell 31.

Figure 10 represents an embodiment of the heat roller 30 according to the invention.
30 In this embodiment the resistance layer 32 is arranged directly on the roller shell 31 and is covered essentially completely by two electrodes 33 and 34 on its side facing

away from the roller shell 31. The electrodes 33 and 34 are electrically separated from each other by an insulation 36.

Conventional dielectrics such as air or plastic can be used as material for the
5 insulation 36.

Electrode 34 can be connected with the source of current (not shown) on the left-hand side of the copying roller, electrode 33 can be connected on the right-hand side. In this embodiment, the heating current flows from the first electrode 33 to the roller shell,
10 which preferably consists of a material which is a good electric conductor, and then back from the roller shell through the resistive mass 33 to the other electrode 34 or vice versa.

If the at least two electrodes are arranged on one side of the resistance layer and an
15 interlayer consisting of a material with high conductivity is provided on the opposite side, the heating current will flow from one electrode through the resistance layer to the interlayer, further through this layer, and then through the resistance layer to the other electrode. However, on account of the resistive material, it will also be possible to work without an interlayer, even where the roller shell consists of a nonconducting
20 material. In this case the heating current flows through the resistance layer, where because of the polymer structure the entire resistive mass heats up. Finally, even the roller shell can consist of conducting material and serve to conduct the current. The current applied to the electrodes then flows from one electrode through the resistive mass, flows further through the roller shell, and then through the resistive mass to the
25 other electrode.

In all these embodiments where the current is fed to the resistive mass from one side, the voltage prevailing in the zones is reduced to half that with two-sided current supply.

The distance provided between the electrodes acts as an additional resistance in parallel. With air as the insulator 36, the resistance is determined by the distance between the electrodes and thus by the surface resistance.

- 5 It is also possible to use a resistance-heating element as in figure 2. This resistance-heating element is used in the heat roller according to the invention in such a way that the side of the resistance-heating element on which the contacted electrodes are arranged is facing away from the roller shell. The electrical dimensions are determined according to the diagrammatical sketch 3 and associated mathematical
10 relations when such a resistance-heating element is used.

Known insulation in the form of polyester, polyimide and other foils can be provided between the resistance-heating element and the roller shell if it is desired to keep the surface of the heat roller voltage-free. Power supply to the electrodes is provided
15 preferably by known contact-making technologies in the case of flat heating elements or via slip rings or bearings serving as electrical contact terminals.

Depending on the particular application, metal foils or sheets can for instance be used as electrodes. It is also within the scope of the invention to clamp the resistance-
20 heating element by clamping devices to the roller shell. Locking rings which can simultaneously serve as electrodes can for instance be used as a clamping device. Thermoplastics in the form of foils or heat-conducting pastes can be provided between the resistance-heating element and the roller shell in order to improve the heat transfer between the resistance-heating element and the roller shell.

25

In the roller according to the invention, several resistance-heating elements which are spaced apart and distributed over the length of the roller can be provided inside the roller. It is also within the spirit of the invention, however, to provide inside the roller one continuous resistance layer to which several electrodes are applied in the form of
30 segments. These segments extend over the full inner periphery of the roller shell that is covered by the resistance layer, and can readily be introduced into the roller. They thus permit a rapid assembly. It is moreover possible to achieve heating of individual

regions of the roller by providing in the heat roller according to the invention a number of electrodes acting as electrode pairs which are alternatively supplied with current. These electrodes, too, preferably extend over the full periphery and are spaced apart in an axial direction. For instance, the marginal regions of the roller can
5 be heated extra when the heat roller is used as a foil coating roller. This additional heat supply can provide a uniform temperature distribution over the region in contact with the goods to be heated, since a temperature drop along the margins is balanced by the additional heating.

10 Within the scope of the invention, it is also possible to select a resistive mass that has a negative temperature coefficient of electric resistance. In such an embodiment, very low making currents are needed. In the resistive mass according to the invention, the temperature coefficient of electric resistance can become positive above a certain temperature, for instance 80 °C.

15

In the interior of the roller, a thermal insulating material which, if necessary, can completely fill the interior of the roller can be provided on the side of the electrodes facing away from the resistance layer. This thermal insulating material prevents a radiation of heat from the resistance-heating element toward the interior of the roller
20 and hence an accumulation of heat inside the roller.

Because of the resistance layer and contact arrangement employed, the roller according to the invention can be operated, both with low voltages of for instance 24 V and with very high voltages of for instance 240, 400 and up to 1000 V.

25

With the roller according to the invention, heating powers per unit area in excess of 10 kW/m² and preferably in excess of 30 kW/m² can be achieved. With the heat roller, heating powers of up to 60 kW/m² can be achieved. Such a heating power of up to 60 kW/m² can even be achieved with a layer thickness of the resistance layer of 1 mm.

30 The time-dependent drop in heating power can be smaller than 0.01 % per year when a voltage of 240 V is continuously applied.

The temperature that can be achieved with the roller is limited by the thermal properties of the polymer selected, but can be higher than 240 °C and up to 500 °C.

5 The heat roller according to the invention is particularly adapted to be used as a copying roller in photocopying equipment or as a foil coating roller for the sealing of materials with foils.

According to the invention, polymers which are conductive through metal or semimetal atoms attached to the polymers can be used in particular as the
10 electroconductive polymer in the resistance layers of the resistance-heating element, the heatable pipe and the heat roller. The polymers preferably have a specific resistance to current flow in the range of values attained with semiconductors. It can have values up to 10^2 and preferably at most 10^5 Ω -cm. Such polymers can be obtained by a process where metal or semimetal compounds or their solutions are
15 added to polymer dispersions, polymer solutions or polymers in such an amount that approximately one metal or semimetal atom is present per polymer molecule. To this mixture a reducing agent is added in a small excess, or metal or semimetal atoms are formed by known thermal decomposition. After that the ions formed or still present are washed out while graphite or carbon black can, if necessary, be added to the
20 dispersion solution or granulated material.

The electroconductive polymers used according to the invention are preferably free of metal ions. The maximum content of free ions is 1 wt.% related to the total mass of the resistance layer. The ions are either washed out as described above, or a suitable
25 reducing agent is added. The reducing agent is added in a ratio such that the ions can be completely reduced. The low proportion of ions and preferably absence of ions in the electroconductive polymers used according to the invention leads to a long-term stability of the resistance layer subject to electric currents. It was revealed that polymers which contain a higher percentage of ions have a low aging resistance when
30 subject to electric currents, since electrolysis reactions lead to spontaneous destruction of the resistance layer. The electroconductive polymer used according to the invention, to the contrary, is aging-resistant because of its low ion concentration, even

under prolonged current flow. Reducing agents for the above process of preparing an electroconductive polymer used according to the invention are those which either will not form ions because they are thermally decomposed during processing, such as hydrazine, or which chemically react with the polymer itself, such as formaldehyde, or reducing agents such as hypophosphite, where an excess or reaction products are readily washed out. Preferred metals or semimetals are silver, arsenic, nickel, graphite or molybdenum. Metal or semimetal compounds which yield the metal or semimetal without disturbing reaction products by purely thermal decomposition are particularly preferred. Arsenic hydride or nickel carbonyl have been found to be particularly advantageous. The electroconductive polymers used according to the invention can for instance be prepared by adding to the polymer a premix prepared according to one of the following formulations in an amount of 1 to 10 wt.% (referred to the polymer).

Example 1: 1470 parts by weight of a dispersion of fluorohydrocarbon polymer (55 % solids in water), 1 part by weight of wetting agent, 28 parts by weight of 10 % silver nitrate solution, 6 parts by weight of chalk, 8 parts by weight of ammonia, 20 parts by weight of carbon black, 214 parts by weight of graphite, 11 parts by weight of hydrazine hydrate.

Example 2: 1380 parts by weight of a 60 % acrylic resin dispersion in water, 1 part by weight of wetting agent, 32 parts by weight of 10 % silver nitrate solution, 10 parts by weight of chalk, 12 parts by weight of ammonia, 6 parts by weight of carbon black, 310 parts by weight of graphite, 14 parts by weight of hydrazine hydrate.

Example 3: 2200 parts by weight of distilled water, 1000 parts by weight of styrene (monomer), 600 parts by weight of ampholytic soap (15 %), 2 parts by weight of sodium pyrophosphate, 2 parts by weight of potassium persulfate, 60 parts by weight of nickel sulfate, 60 parts by weight of sodium hypophosphite, 30 parts by weight of adipic acid, 240 parts by weight of graphite.

Claims



1. Flat heating element (1), comprising a thin resistance layer (2) containing an
5 intrinsically electroconductive polymer and at least two flat electrodes (3, 4)
arranged on one side of the resistance layer (2) at a distance from each other.
2. Heating element according to claim 1, characterized in that a flat floating elec-
trode (5) is arranged on the side of the resistance layer (2) that is opposite to the
10 two flat electrodes (3, 4).
3. Heating element according to one of the claims 1 and 2, characterized in that the
electrodes (3, 4, 5) consist of a material with a specific electric resistance of less
than $10^{-4} \Omega\text{-cm}$, preferably of less than $10^{-5} \Omega\text{-cm}$.
- 15 4. Heating element according to one of the preceding claims, characterized in that
the electrodes (3, 4, 5) have a thickness in the range of 50 to 150 μm , preferably of
75 to 100 μm .
- 20 5. Heating element according to one of the preceding claims, characterized in that
the resistance layer has a thickness of 0.1 to 2 mm, preferably 1 mm.
6. Heating element according to one of the preceding claims, characterized in that
the resistance layer (2) has a positive temperature coefficient of electric resistance.
- 25 7. Heating element according to one of the preceding claims, characterized in that
the resistance layer (2) is metallized on its surfaces facing the electrodes (3, 4) and
the floating electrode (5).
- 30 8. Heating element according to one of the preceding claims, characterized in that
the intrinsically electroconductive polymer is doped.

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9. Heating element according to claim 8, characterized in that the doping is a metal or semimetal doping.
10. Heating element according to one of the claims 8 or 9, characterized in that for
5 doping, dopant was added to the polymer in an amount such that the ratio between atoms of the dopant and the number of polymer molecules is at least 1:1, preferably between 2:1 and 10:1.
11. Heating element according to one of the preceding claims, characterized in that
10 the resistance layer (2) in addition contains graphite particles.
12. Heating element according to claim 11, characterized in that the graphite particles are present in an amount of at most 20 vol.%, preferably of at most 5 vol.%, referred to the total volume of the resistance layer, and have an average diameter
15 of at most 0.1 μm .
13. Heating element according to one of the preceding claims, characterized in that the content of free ions in the resistance layer is at most 1 wt.% referred to the total weight of the resistance layer.
- 20 14. Heating element according to one of the preceding claims, characterized in that the intrinsically electroconductive polymer comprises polyamide, acrylic, epoxides or polyurethanes.
- 25 15. Heating element according to one of the preceding claims, characterized in that the resistance layer (2) comprises a support material.
16. Heating element according to claim 14, characterized in that the support material is a flat porous, electrically insulating material.
- 30 17. Heatable pipe (10) in which an inner pipe (11) on its outer surface is covered at least in part, directly or via an interlayer (15), with a thin resistance layer (12)





containing an intrinsically electroconductive polymer and on the outer surface of the resistance layer (12) at least two flat electrodes (13, 14) which cover the resistance layer (12) at least in part are arranged at a distance from each other.

- 5 18. Pipe according to claim 17, characterized in that an interlayer (15) of a material having a high electrical conductivity is arranged between the inner pipe (11) and the resistance layer (12).
- 10 19. Pipe according to claim 17, characterized in that the resistance layer (12) is arranged directly on the inner pipe (11) and the inner pipe (11) consists of a material having a high electric conductivity.
- 15 20. Pipe according to one of the claims 17 to 19, characterized in that the resistance layer (12) and the electrodes (13, 14) arranged on it extend longitudinally in an axial direction and the electrodes (13, 14) are arranged on the resistance layer (12) in a peripherally spaced apart relationship.
- 20 21. Pipe according to claim 20, characterized in that the resistance layer (12) covers only part of the periphery of the inner pipe (11) and extends longitudinally in an axial direction.
- 25 22. Pipe according to one of the claims 17 to 21, characterized in that the electrodes (13, 14) and the interlayer (15) consist of a material having a specific electric resistance of less than $10^{-4} \Omega\text{-cm}$, preferably less than $10^{-5} \Omega\text{-cm}$.
23. Pipe according to one of the claims 17 to 22, characterized in that the electrodes (13, 14) and the interlayer (15) have a thickness in the range of 50 to 150 μm , preferably of 75 to 100 μm .
- 30 24. Pipe according to one of the claims 17 to 23, characterized in that the resistance layer (12) has a thickness of 0.1 to 2 mm, preferably of 1 mm.





25. Pipe according to one of the claims 17 to 24, characterized in that the resistance layer (12) has a positive temperature coefficient of electric resistance.
26. Pipe according to one of the claims 17 to 25, characterized in that the resistance layer (12) is metallized at its surfaces facing the electrodes (13, 14) and the inter-layer (15).
27. Pipe according to one of the claims 17 to 26, characterized in that the intrinsically electroconductive polymer is doped.
28. Pipe according to claim 27, characterized in that the doping is a metal or semi-metal doping.
29. Pipe according to one of the claims 27 or 28, characterized in that for doping, a dopant was added to the polymer in an amount such that the ratio between atoms of the dopant and the number of polymer molecules is at least 1:1, preferably between 2:1 and 10:1.
30. Pipe according to one of the claims 17 to 29, characterized in that the resistance layer (12) additionally contains graphite particles.
31. Pipe according to claim 30, characterized in that the graphite particles are present in an amount of at most 20 vol.%, preferably of at most 5 vol.%, referred to the total volume of the resistance layer, and have an average diameter of at most 0.1 μm .
32. Pipe according to one of the claims 17 to 31, characterized in that the content of free ions in the resistance layer is at most 1 wt.%, referred to the total weight of the resistance layer.

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41. Transportation device according to claim 38, characterized in that the resistance layer (12) covers only part of the periphery of the inner pipe (11) and extends longitudinally in an axial direction.
- 5
42. Transportation device according to one of the claims 36 to 41, characterized in that the electrodes (23, 24) consist of a material with a specific electric resistance of less than $10^{-4} \Omega \cdot \text{cm}$, preferably of less than $10^{-5} \Omega \cdot \text{cm}$.
- 10
43. Transportation device according to one of the claims 36 to 42, characterized in that the electrodes (23, 24) have a thickness in the range of 50 to 150 μm , preferably of 75 to 100 μm .
- 15
44. Transportation device according to one of the claims 36 to 43, characterized in that the resistance layer (22) has a thickness of 0.1 to 2 mm.
- 20
45. Transportation device according to one of the claims 36 to 44, characterized in that the resistance layer (22) has a positive temperature coefficient of electric resistance.
- 25
46. Transportation device according to one of the claims 36 to 45, characterized in that the resistance layer (22) is metallized on its surfaces facing the electrodes (23, 24) and the interlayer (25).
47. Transportation device according to one of the claims 36 to 46, characterized in that the intrinsically electroconductive polymer is doped.
48. Transportation device according to claim 47, characterized in that the doping is a metal or semimetal doping.
- 30
49. Transportation device according to one of the claims 47 or 48, characterized in that for doping, an amount of dopant was added to the polymer in an amount such



that the ratio between atoms of the dopant and the number of polymer molecules is at least 1:1, preferably between 2:1 and 10:1.

50. Transportation device according to one of the claims 36 to 49, characterized in
5 that the resistance layer (22) additionally contains graphite particles.

51. Transportation device according to claim 50, characterized in that the graphite
particles are present in an amount of at most 20 vol.%, preferably of at most 5
vol.%, referred to the total volume of the resistance layer, and have an average
10 diameter of at most 0.1 μm .

52. Transportation device according to one of the claims 36 to 51, characterized in
that the content of free ions in the resistance layer is at most 1 wt.%, referred to
the total weight of the resistance layer.

15

53. Transportation device according to one of the claims 36 to 52, characterized in
that the intrinsically electroconductive polymer comprises polyamide, acrylic,
epoxides or polyurethanes.

20 54. Transportation device according to one of the claims 36 to 52, characterized in
that the resistance layer (22) comprises a support material.

55. Transportation device according to claim 55, characterized in that the support
material is a flat porous, electrically insulating material.

25

56. Transportation device according to one of the claims 36 to 58, characterized in
that this comprises a power supply installation (29) which extends outside the
container (21) in an axial direction over the entire length of the container (21) and
is connected with each of the electrodes (23, 24) in at least two contact points.

30

57. Heat roller (30), comprising a roller shell (31) and at least one flat resistance-
heating element arranged on the inner surface of the roller shell (31), where the



resistance-heating element consists of at least two flat electrodes (33, 34) and a thin resistance layer (32) containing an intrinsically electroconductive polymer.

- 5 58. Heat roller according to claim 57, characterized in that the resistance layer (32) is arranged between the flat electrodes (33, 34) and that the electrodes (33, 34) cover this layer at least in part.
- 10 59. Heat roller according to claim 57 or 58, characterized in that the at least two flat electrodes (33, 34) are arranged on the side of the resistance layer (32) facing away from the roller shell (31) at a distance from each other.
- 15 60. Heat roller according to claim 59, characterized in that an interlayer (35) consisting of a material with high electric conductivity is arranged between the resistance layer (32) and the roller shell (31).
- 20 61. Heat roller according to one of the claims 59 and 60, characterized in that the electrodes (33, 34) essentially extend over the entire periphery and are arranged in an axially spaced apart relationship.
- 25 62. Heat roller according to one of the claims 57 to 61, characterized in that the resistance layer (32) has a structure where different resistive materials with different specific electric resistances are present in layers.
- 30 63. Heat roller according to one of the claims 57 to 62, characterized in that the electrodes (33, 34) and the interlayer (35) consist of a material with a specific electric resistance of less than $10^{-4} \Omega\cdot\text{cm}$, preferably of less than $10^{-5} \Omega\cdot\text{cm}$.
64. Heat roller according to one of the claims 57 to 63, characterized in that the electrodes (33, 34) and the interlayer (35) have a thickness in the range of 50 to 150 μm , preferably of 75 to 100 μm .



65. Heat roller according to one of the claims 57 to 64, characterized in that the resistance layer has a thickness of 0.1 to 2 mm, preferably of 1 mm.
66. Heat roller according to one of the claims 57 to 65, characterized in that the resistance layer (32) has a positive temperature coefficient of electric resistance.
67. Heat roller according to one of the claims 57 to 66, characterized in that the resistance layer (32) is metallized on its surfaces facing the electrodes (33, 34) and the interlayer (35).
68. Heat roller according to one of the claims 57 to 67, characterized in that the intrinsically electroconductive polymer is doped.
69. Heat roller according to claim 68, characterized in that the doping is a metal or semimetal doping.
70. Heat roller according to one of the claims 68 or 69, characterized in that for doping, an amount of dopant was added to the polymer in an amount such that the ratio between atoms of the dopant and the number of polymer molecules is at least 1:1, preferably between 2:1 and 10:1.
71. Heat roller according to one of the claims 57 to 70, characterized in that the resistance layer (32) additionally contains graphite particles.
72. Heat roller according to claim 71, characterized in that the graphite particles are present in an amount of at most 20 vol.%, preferably of at most 5 vol.%, referred to the total volume of the resistance layer, and have an average diameter of at most 0.1 μm .
73. Heat roller according to one of the claims 57 to 72, characterized in that the content of free ions in the resistance layer is at most 1 wt.%, referred to the total weight of the resistance layer.



74. Heat roller according to one of the claims 57 to 73, characterized in that the intrinsically electroconductive polymer comprises polyamide, acrylic, epoxides or polyurethanes.

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75. Heat roller according to one of the claims 57 to 74, characterized in that the resistance layer (32) comprises a support material.

76. Heat roller according to claim 75, characterized in that the support material is a flat porous, electrically insulating material.

10