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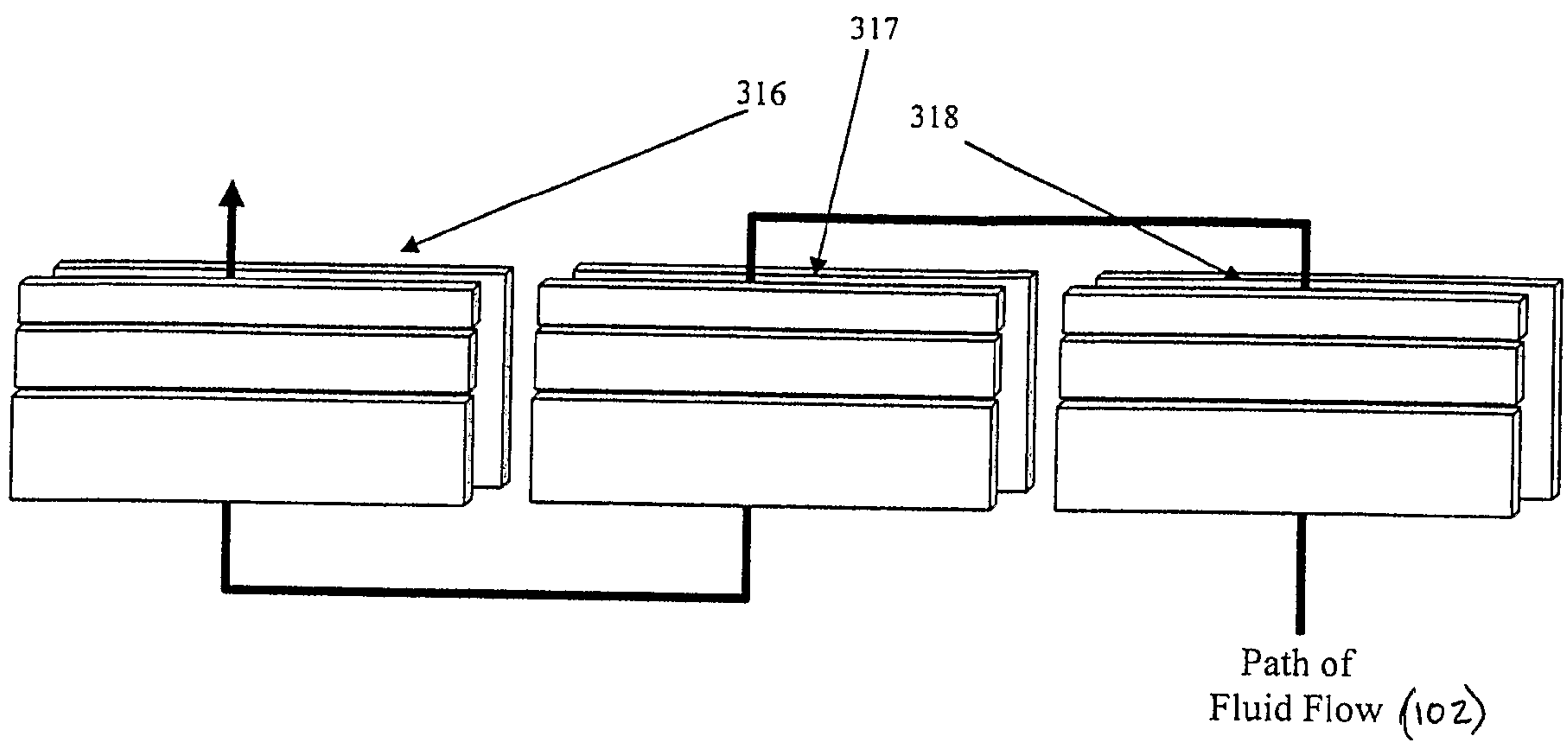

(57) Abrégé/Abstract:
A fluid heating apparatus has a fluid flow path from an inlet to an outlet, with multiple heating sections positioned along the flow path. Each heating section is at least one pair of electrodes between which an electric current is passed through the fluid to resistively heat the fluid during its passage along the flow path. At least one of the heating sections has a segmented electrode made up of a plurality of electrically separable segments. This allows an effective active area of the segmented electrode to be controlled by selectively activating the segments. A controller determines a required voltage and current to be delivered to the fluid by each heating section, and allows for input conductivity as well as variations in fluid conductivity with temperature. The controller activates selected segments of the segmented electrode to effect delivery of desired current and voltage by the segmented electrode to the fluid.

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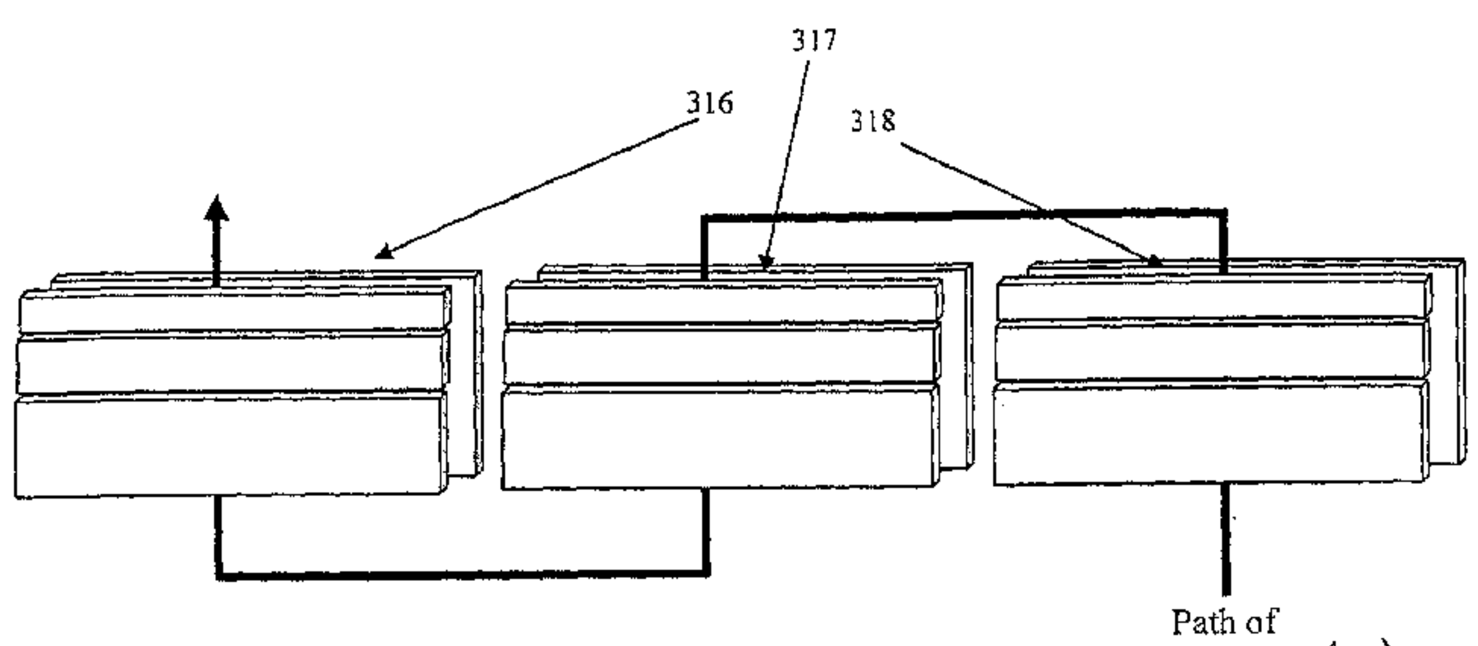

Figure 3

(57) Abstract: A fluid heating apparatus has a fluid flow path from an inlet to an outlet, with multiple heating sections positioned along the flow path. Each heating section is at least one pair of electrodes between which an electric current is passed through the fluid to resistively heat the fluid during its passage along the flow path. At least one of the heating sections has a segmented electrode made up of a plurality of electrically separable segments. This allows an effective active area of the segmented electrode to be controlled by selectively activating the segments. A controller determines a required voltage and current to be delivered to the fluid by each heating section, and allows for input conductivity as well as variations in fluid conductivity with temperature. The controller activates selected segments of the segmented electrode to effect delivery of desired current and voltage by the segmented electrode to the fluid.

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"Segmented rapid heating of fluid"

Technical Field

The present invention relates to an apparatus, a system and method for the rapid heating of fluid and more particularly, to an apparatus, system and method for rapidly heating fluid using electrical energy.

Background of the Invention

Hot water systems of one form or another are installed in the vast majority of residential and business premises in developed countries. In some countries, the most common energy source for the heating of water is electricity.

Of course, as is generally known, the generation of electricity by the burning of fossil fuels significantly contributes to pollution and global warming. For example, in 1996, the largest electricity consuming sector in the United States were residential households, which were responsible for 20% of all carbon emissions produced. Of the total carbon emissions from this electricity-consuming sector, 63% were directly attributable to the burning of fossil fuels used to generate electricity for that sector.

In developed nations, electricity is now considered a practical necessity for residential premises and with electricity consumption per household growing at approximately 1.5% per annum since 1990 the projected increase in electricity consumption for the residential sector has become a central issue in the debate regarding carbon emission stabilisation and meeting the goals of the Kyoto Protocol.

From 1982 to 1996 the number of households in the United States increased at a rate of 1.4% per annum and residential electricity consumption increased at a rate of 2.6% per annum for the same period. Accordingly, the number of households in the United States is projected to increase by 1.1% per annum through to the year 2010 and residential electricity consumption is expected to increase at a rate of 1.6% per annum for the same period.

It was estimated in 1995 that approximately 40 million households worldwide used electric water heating systems. The most common form of electric hot water heating system involves a storage tank in which water is heated slowly over time to a predetermined temperature. The water in the storage tank is maintained at the predetermined temperature as water is drawn from the storage tank and replenished with cold inlet water. Generally, storage tanks include a submerged electrical resistance-heating element connected to the mains electricity supply whose operation is controlled by a thermostat or temperature-monitoring device.

Electric hot water storage systems are generally considered to be energy inefficient as they operate on the principle of storing and heating water to a predetermined temperature greater than the temperature required for usage, even though the consumer may not require hot water until some future time. As thermal energy is lost from the hot water in the storage tank, further consumption of electrical energy may be required to reheat that water to the predetermined temperature. Ultimately, a consumer may not require hot water for some considerable period of time. However, during that time, some electric hot water storage systems continue to consume energy to heat the water in preparation for a consumer requiring hot water at any time.

Rapid heating of water such that the water temperature reaches a predetermined level within a short period of time enables a system to avoid the inefficiencies that necessarily occur as a result of storing hot water. Rapid heating or "instant" hot water systems are currently available where both gas, such as natural gas or LPG (Liquefied Petroleum Gas) and electricity are used as the energy source. In the case of natural gas and LPG, these are fuel sources that are particularly well suited to the rapid heating of fluid as the ignition of these fuels can impart sufficient thermal energy transfer to fluid and raise the temperature of that fluid to a satisfactory level within a relatively short time under controlled conditions.

However, whilst it is possible to use natural gas fuel sources for the rapid heating of water, these sources are not always readily available. In contrast, an electricity supply is readily available to most households in developed nations.

There are other existing electrical "instant" hot water systems. One method of heating is known as the hot wire system wherein a wire is located in an electrically non-conductive environment or housing. In operation, water passes through the environment or over the wire housing in contact with and in very close proximity to the wire or wire housing. The wire being energised will heat up as a result and thereby transfer thermal energy to the water. Control is generally effected by monitoring the output temperature of water and comparing it with a predetermined temperature setting. Dependent upon the monitored output temperature of the water, a controlled voltage is applied to the wire until the temperature of the water reaches the desired predetermined temperature setting.

Whilst the hot wire type of system avoids the energy inefficiencies involved with the storage of hot water, it unfortunately suffers a number of other disadvantages. In particular, it is necessary to heat the wire to temperatures much greater than that of the surrounding water. This has the disadvantageous effect of causing the formation of crystals of dissolved salts normally present in varying concentrations in water such as calcium carbonate and calcium sulphate. Hot areas of the wire or housing in direct contact with the water provide an excellent environment for the formation of these types of crystals which results in the wire or housing becoming "caked" and thus reducing the efficiency of thermal transfer from the wire to the surrounding water. As the tube is generally relatively small in diameter, the formation of crystals can also reduce the flow of water through the tube. In addition, hot wire type systems require relatively high water pressures for effective operation and thus these systems are not effective for use in regions that have relatively low water pressure or frequent drops in water pressure that may occur during times of peak water usage.

Yet another proposed instant hot water system is the electromagnetic induction system, which functions like a transformer. In this case currents induced into a secondary winding of the transformer cause the secondary winding to heat up. The heat generated here is dissipated by circulating water through a water jacket that surrounds the secondary winding. The heated water is then passed out of the system for usage. Control is generally effected by monitoring the output temperature of water from the water jacket and comparing it with a predetermined temperature setting. Dependent upon the monitored output temperature of the water, voltage applied to the primary winding can be varied, which varies the electric currents induced in the secondary winding, until the temperature of the water reaches the desired predetermined temperature setting.

Whilst the electromagnetic induction type of system avoids the energy inefficiencies involved with the storage of hot water, it also suffers a number of other disadvantages. In particular, it is necessary to heat the secondary winding to temperatures greater than that of the surrounding water. This has the same effect of causing the formation of crystals of dissolved salts as discussed above. As the gap between the secondary winding and the surrounding water jacket is generally relatively narrow, the formation of crystals can also reduce the flow of water through the jacket. In addition, the magnetic fields developed and the high currents induced in the secondary winding may result in unacceptable levels of electrical or RF noise. This electrical or RF noise can be difficult to suppress or shield, and affects other electromagnetic susceptible devices within range of the electromagnetic fields.

Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is solely for the purpose of providing a context for the present invention. It is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present invention as it existed before the priority date of each claim of this application.

Throughout this specification the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

Summary of the Invention

According to a first aspect the present invention provides a method for heating fluid, the method comprising:

passing the fluid along a flow path from an inlet to an outlet, the flow path comprising at least first and second heating sections positioned along the flow path such that fluid passing the first heating section subsequently passes the second heating section, each heating section comprising at least one pair of electrodes between which an electric current is passed through the fluid to resistively heat the fluid during its passage along the flow path, and wherein at least one of said heating sections comprises at least one segmented electrode, the segmented electrode comprising a plurality of electrically separable segments allowing an effective active area of the segmented electrode to be controlled by selectively activating the segments such that upon application of a voltage to the segmented electrode, current drawn will depend upon the effective active area;

measuring fluid conductivity at the inlet;

determining from measured fluid conductivity a required voltage and current to be delivered to the fluid by the first heating section to raise the fluid temperature by a first desired amount;

determining an altered fluid conductivity resulting from operation of the first heating section;

determining from the altered fluid conductivity a required voltage and current to be delivered to the fluid by the second heating section to raise the fluid temperature by a second desired amount; and activating segments of the segmented electrode in a manner to effect delivery of desired current and voltage by the segmented electrode.

According to a second aspect the present invention provides an apparatus for heating fluid, the apparatus comprising:

a fluid flow path from an inlet to an outlet;

at least first and second heating sections positioned along the flow path such that fluid passing the first heating section subsequently passes the second heating section, each heating section comprising at least one pair of electrodes between which an electric current is passed through the fluid to resistively heat the fluid during its passage along the flow path, and wherein at least one of said heating sections comprises at least one segmented electrode, the segmented electrode comprising a plurality of electrically separable segments allowing an effective active area of the segmented electrode to be controlled by selectively activating the segments such that upon application of a voltage to the segmented electrode current drawn will depend upon the effective active area;

a conductivity sensor for measuring fluid conductivity at the inlet; and

a controller for determining from measured fluid conductivity a required voltage and current to be delivered to the fluid by the first heating section to raise the fluid temperature by a first desired amount, for determining an altered fluid conductivity resulting from operation of the first heating section, for determining from the altered fluid conductivity a required voltage and current to be delivered to the fluid by the second heating section to raise the fluid temperature by a second desired amount, and for activating segments of the segmented electrode in a manner to effect delivery of desired current and voltage by the segmented electrode combination selected.

By providing a segmented electrode and selectively activating segments of the segmented electrode, the present invention provides for control over a voltage/current regime in which that heating section will operate. This permits embodiments of the invention to offer better adaptability to the variability of electrical conductivity of fluid between different locations and/or different times while remaining within voltage and current limits.

In preferred embodiments of the invention, variations in fluid conductivity are substantially continually accommodated in response to measurements of incoming fluid conductivity. Fluid conductivity may also be determined by reference to the current drawn upon application of a voltage across one or more electrodes of one or more heating sections.

Variations in fluid conductivity will cause changes in the amount of electrical current drawn by the system. Preferred embodiments of the invention prevent such variations from causing the peak current to exceed rated values, by using the measured conductivity value to initially select an established, commensurate combination of segments of the electrode before allowing the system to operate. In such embodiments the combined surface area of the selected electrode segments is specifically calculated to ensure that the rated maximum electrical current values of the system are not exceeded.

Further preferred embodiments of the invention utilise the measured fluid conductivity to ensure that no violation occurs of a predetermined range of acceptable fluid conductivity within which the system is designed to operate.

In preferred embodiments of the invention, each heating section comprises a segmented electrode. Such embodiments allow the effective electrode area of each heating section to be controlled by selectively activating segments of the segmented electrode of that heating section.

The or each segmented electrode is preferably divided into segments of varying size, to permit combinations of segments to be selected to provide an increased accuracy of selection of desired effective area. For example, where the segmented electrode is divided into three segments, the segments preferably have relative effective areas in a ratio of 1:2:4, that is, the segments preferably constitute four sevenths, two sevenths and one seventh of the total effective electrode area, respectively. In such embodiments appropriate activation of the three electrode segments permits selection of any one of seven available effective areas. Alternative segment area ratios and numbers of segments may be provided.

In a preferred embodiment, each electrode segment of the segmented electrode extends substantially perpendicularly to a direction of fluid flow, so as to subject fluid across substantially the entire fluid flow path to resistive heating.

Further, electrode segment selection is preferably carried out in a manner to ensure peak current limits are not exceeded. In such embodiments, the measurement of inlet conductivity permits operation of the device to be prevented if such current limits will not safely be met.

In embodiments in which fluid flow rate is not substantially constant or is unknown, a fluid flow rate meter is preferably provided to assist in determining appropriate control of current, voltage and electrode segment activation under varying fluid flow rates.

Moreover, by providing a plurality of heating sections, the present invention allows each heating section to be operated in a manner that allows for changes in electrical conductivity of the fluid with increasing fluid temperature. For example, water conductivity increases with temperature, on average by around 2% per degree Celsius. Where fluid is to be heated by scores of degrees Celsius, for example from room temperature to 60 degrees Celsius or 90 degrees Celsius, inlet fluid conductivity can be substantially different to outlet fluid conductivity. Sequentially subjecting the fluid to resistive heating at successive heating sections along the flow path allows each heating section to operate within a constrained temperature range. Thus each heating section may apply voltage and current which is applicable to the fluid conductivity within that limited temperature range rather than attempting to apply voltage and current in respect of a single or averaged conductivity value across the entire temperature range.

Embodiments of the invention preferably further comprise a downstream fluid thermometer to measure fluid temperature at the outlet, to permit feedback control of the fluid heating.

Preferably, each heating section comprises substantially planar electrodes between which the fluid flow path passes. Alternatively, each heating section may comprise substantially coaxial cylindrical or flat electrodes with the fluid flow path comprising a space of annular cross section. The fluid flow path may define a plurality of parallel flow paths for the fluid.

In one embodiment, a second temperature measuring means measures the temperature of the fluid between the first and second heating sections, and the control means controls power to the first and second heating sections in accordance with the measured temperatures and a desired fluid temperature increase in each respective heating section.

Other embodiments of the invention may comprise three or more heating sections, each section having an inlet and an outlet, the sections being connected in series and the control means initially selecting electrode segments in accordance with the measured incoming fluid conductivity and controlling power to an electrode pair of each section in accordance with measured inlet and outlet temperatures of each section and a predetermined desired temperature difference for each section.

In preferred embodiments of the invention the control means supplies a varying voltage to the electrode pair of each heating section, by delivering selected full-wave cycles from AC mains supply voltage. For example, full wave cycles may be delivered at a cycle frequency determined by a pulse control system and being an integer fraction of AC mains supply voltage frequency, so that control of the power supplied to the selected combination of electrode segments includes varying the number of control pulses per unit time.

The desired temperature of the outlet fluid may be adjusted by a user via an adjustable control means.

The volume of fluid passing between any set of electrodes is preferably determined by measuring the dimensions of the passage within which the fluid is exposed to the electrodes taken in conjunction with fluid flow.

Similarly, the time for which a given volume of fluid will receive electrical power from the electrodes may be determined by reference to the flow rate of fluid through the fluid flow path. The temperature increase of the fluid is proportional to the amount of electrical power applied to the fluid. The amount of electrical power required to raise the temperature of the fluid a known amount, is proportional to the mass (volume) of the fluid being heated and the fluid flow rate through the passage. The measurement of electrical current flowing through the fluid can be used as a measure of the electrical conductivity, or the specific conductance of that fluid, and hence allows selection of segments to be activated together with control and management of the required change in applied voltage required to keep the applied electrical power constant or at a desired level. The electrical conductivity, and hence the specific conductance of the fluid being heated will change with rising temperature, thus causing a specific conductance gradient along the path of fluid flow.

The energy required to increase the temperature of a body of fluid may be determined by combining two relationships:

<u>Relationship (1)</u>

Energy = Specific Heat Capacity x Density x Volume x Temp-Change

or

The energy per unit of time required to increase the temperature of a body of fluid may be determined by the relationship:

$$\text{Power (P)} = \frac{\text{Specific Heat Capacity(SHC) x Density x Vol (V) x Temp-Change (Dt)}}{\text{Time (T)}}$$

For analysis purposes, the specific heat capacity of water, for example, may be considered as a constant between the temperatures of 0degC and 100 degC. The density of water being equal to 1, may also be considered constant. Therefore, the amount of energy required to change the temperature of a unit mass of water, 1 degC in 1 second is considered as a constant and can be labelled "k". Volume/Time is the equivalent of flow rate (Fr). Thus the energy per unit of time required to increase the temperature of a body of fluid may be determined by the relationship:

$$\text{Power (P)} = \frac{\text{k x Flow rate (Fr) x Temp-Change (Dt)}}{\text{Time (T)}}$$

Thus if the required temperature change is known, the flow rate can be determined and the power required can be calculated.

Typically, when a user requires heated water, a tap is operated thus causing water to flow through the fluid flow path. This flow of water may be detected by a flow rate meter and cause the initiation of a heating sequence. The temperature of the inlet water may be measured and compared with a preset desired temperature for water output from the system. From these two values, the required change in water temperature from inlet to outlet may be determined.

Of course, the temperature of the inlet water to the segmented electrode sections may be repeatedly measured over time and as the value for the measured inlet water temperature changes, the calculated value for the required temperature change from inlet to outlet of the segmented electrode sections can be adjusted accordingly. Similarly, with changing temperature, mineral content and the like, changes in electrical conductivity and therefore specific conductance of the fluid may occur over time. Accordingly, the current passing through the fluid will change causing the resulting power applied to the water to change, and this may be managed by selectively activating or deactivating segments of the segmented electrode(s) within the section. Repeatedly measuring the temperature outputs of the heating sections over time and comparing these with the calculated output temperature values will enable repeated calculations to continually optimise the voltage applied to the electrodes.

In one preferred embodiment, a computing means provided by the microcomputer controlled management system is used to determine the electrical power that should be applied to the fluid passing between the electrodes, by determining the value of electrical power that will effect the desired temperature change between the heating section inlet and outlet, measuring the effect of changes to the specific conductance of the water and thereby selecting appropriate activation of segments and calculating the voltage that needs to be applied for a given flow rate.

Relationship (2) Control of Electrical Power

In preferred embodiments of the present invention, the electrical current flowing between the electrodes within each heating section, and hence through the fluid, is measured. The heating section input and output temperatures are also measured. Measurement of the electrical current and temperature allows the computing means of the microcomputer controlled management system to determine the power required to be applied to the fluid in each heating section to increase the temperature of the fluid by a desired amount.

In one embodiment, the computing means provided by the microcomputer controlled management system determines the electrical power that should be applied to the fluid passing between the segmented electrodes of each heating section, selects which segments should be activated in each segmented electrode, and calculates the average voltage that needs to be applied to effect the desired temperature change.

Relationship (2) below, facilitates the calculation of the electrical power to be applied as accurately as possible, almost instantaneously. When applied to water heating systems, this eliminates the need for unnecessary water usage otherwise required to initially pass through the system before facilitating the delivery of water at the required temperature. This provides the potential for saving water or other fluid.

In the preferred embodiments, having determined the electrical power that should be supplied to the fluid passing between the electrodes, the computing means may then calculate the voltage that should be applied to each electrode section (ES) as follows. Once the power required for the electrode section has been calculated, and the current drawn by the electrode (*n*) has been measured (which for segmented electrodes comprises the total current drawn by the activated segment(s) of the segmented electrode section), then:

Relationship (2)

$$\text{Voltage ES}_n\ (V_{\text{app}n})=\text{Power ES}_n\ (P_{\text{req}n})/\text{Current ES}_n(I_{sn})$$
$$V_{\text{app}n} = P_{\text{req}n} / I_{sn}$$

As part of the initial heating sequence, the applied voltage may be set to a relatively low value in order to determine the initial specific conductance of the fluid passing between the electrodes. The application of voltage to the electrodes will cause current to be drawn through the fluid passing therebetween thus enabling determination of the specific conductance of the fluid, being directly proportional to the current drawn therethrough. Accordingly, having determined the electrical power that should be supplied to the fluid flowing between the electrodes in each heating section, it is possible to determine the required voltage that should be applied to those electrodes in order to increase the temperature of the fluid flowing between the electrodes in each heating section by the required amount. The instantaneous current being drawn by the fluid is preferably continually monitored for change along the length of the fluid flow path. Any change in instantaneous current drawn at any position along the passage is indicative of a change in electrical conductivity or specific conductance of the fluid. The varying values of specific conductance apparent in the fluid passing between the electrodes in the electrode sections, effectively defines the specific conductivity gradient along the heating path.

Preferably, various parameters are continuously monitored and calculations continuously performed to determine the electrical power that should be supplied to the fluid and the voltage that should be applied to the electrodes in order to raise the temperature of the fluid to a preset desired temperature in a given period.

Brief Description of the Drawings

An example of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram of a fluid heating system according to one embodiment of the present invention;

Figure 2 is a perspective view of a segmented electrode comprising three segments; and

Figure 3 is a schematic of a fluid flow path passing three heating sections, each heating section comprising one electrode segmented into three segments.

Description of the Preferred Embodiments

Figure 1 is a schematic block diagram of a fluid heating system 100 according to one embodiment of the present invention, in which water is caused to flow through a body 112. The body 112 is preferably made from a material that is electrically non-conductive, such as synthetic plastic material. However, the body 112 is likely to be connected to metallic water pipe, such as copper pipe, that is electrically conductive. Accordingly, earth mesh grids 114 shown in Figure 1 are included at the inlet and outlet of the body 112 so as to electrically earth any metal tubing connected to the apparatus 100. The earth grids 114 would ideally be connected to an electrical earth of the electrical installation in which the heating system of the embodiment was installed. As the earth mesh grids 114 may draw current from an electrode through water passing through the apparatus 100, activation of an earth leakage protection within the control system and/or circuit breaker or residual current device (RCD) may be effected. In a particularly preferred form of this embodiment, the system includes earth leakage circuit protective devices.

When an outlet tap (not shown) is opened, water flows through the body 112 as indicated by flow path arrows 102.

The tube 112, which defines the fluid flow path, is provided with three heating sections comprising respective sets of electrodes 116, 117 and 118. The electrode material may be any suitable metal or a non-metallic conductive material such as conductive plastics material, carbon impregnated material or the like. It is important that the electrodes are selected of a material to minimise chemical reaction and/or electrolysis.

The segmented electrode of each electrode pair, being segmented electrodes 116a, 117a and 118a, is connected to a common switched return path 119 via separate voltage supply power control devices Q1, Q2, ..., Q9, while the other of each electrode pair 116b, 117b and 118b are connected to the incoming single or three phase voltage supply 121, 122 and 123, respectively. The separate voltage supply power control devices Q1, Q2, ..., Q9 switch the common return in accordance with the power management control provided by microprocessor control system 141. The total electrical current supplied to each individual heating section 116, 117 and 118 is measured by current measuring devices 127, 128 and 129, respectively. The current measurements are supplied as an input signal via input interface 133 to microprocessor control system 141 which acts as a power supply controller.

The microprocessor control system 141 also receives signals via input interface 133 from a flow rate measurement device 104 located in the tube 112 and a temperature setting device (not shown) by which a user can set a desired output fluid temperature. The volume of fluid passing between any set of electrodes may be accurately determined by measuring ahead of time the dimensions of the passage within which the fluid is exposed to the electrodes taken in conjunction with fluid flow. Similarly, the time for which a given volume of fluid will receive electrical power from the electrodes may be determined by measuring the flow rate of fluid through the passage. The temperature increase of the fluid is proportional to the amount of electrical power applied to the fluid. The amount of electrical power required to raise the temperature of the fluid a known amount, is proportional to the mass (volume) of the fluid being heated and the fluid flow rate through the passage. The measurement of electrical current flowing through the fluid can be used as a measure of the electrical conductivity, or the specific conductance of that fluid and hence allows determination of the required change in applied voltage required to keep the applied electrical power constant. The electrical conductivity, and hence the specific conductance of the fluid being heated, will change with rising temperature, thus causing a specific conductance gradient along the path of fluid flow.

The microprocessor control system 141 also receives signals via signal input interface 133 from an input temperature measurement device 135 to measure the temperature of input fluid to the tube 112, an output temperature measurement device 136 measuring the temperature of fluid exiting the tube 112, a first intermediate temperature measurement device 138 to measure fluid temperature between the heating sections 116 and 117, and a second intermediate temperature measurement device 139 to measure the temperature of fluid between the heating sections 117 and 118.

The device 100 of the present embodiment is further capable of adapting to variations in fluid conductivity, whether arising from the particular location at which the device is installed or occurring from time to time at a single location. In this regard an input fluid conductivity sensor 106 continually measures the conductivity of fluid at the inlet to the fluid flow path 112. Variations in fluid conductivity will cause changes in the amount of electrical current drawn by each electrode for a given applied voltage. This embodiment monitors such variations and ensures that the device draws a desired level of current by using the measured conductivity value to initially select a commensurate combination of electrode segments before allowing the system to operate. Each electrode 116a, 117a, 118a is segmented into three electrode segments, 116ai, 116aii, 116aiii, 117ai, 117aii, 117aiii, 118ai, 118aii and 118aiii. For each respective electrode, the ai segment is fabricated to typically form about one seventh of the active area of the electrode, the aii segment is fabricated to typically form about two sevenths of the active area of the electrode, and the aiii segment is fabricated to typically form about four sevenths of the active area of the electrode. Selection of appropriate segments or appropriate combinations of segments thus allows the effective area of the electrode to be any one of seven available values for electrode area. Consequently for highly conductive fluid a smaller electrode area may be selected so that for a given voltage the current drawn by the electrode is prevented from rising above desired or safe levels. Conversely, for poorly conductive fluid a larger electrode area may be selected so that for the same given voltage adequate current will be drawn to effect the desired power transfer to the fluid. Selection of segments can be simply effected by activating or deactivating the power switching devices Q1,...Q9 as appropriate.

In particular the combined surface area of the selected electrode segments is specifically calculated to ensure that the rated maximum electrical current values of the system are not exceeded.

The microprocessor control system 141 receives the various monitored inputs and performs necessary calculations with regard to electrode active area selection, desired electrode pair voltages and currents to provide a calculated power to be supplied to the fluid flowing through the passage 112. The microprocessor control system 141 controls the pulsed supply of voltage from each of the three separate phases connected to each of the electrode pairs 116, 117, 118. Each pulsed voltage supply is separately controlled by the separate control signals from the microprocessor control system 141 to the power switching devices Q1, ..., Q9.

It will therefore be seen that, based upon the various parameters for which the microprocessor control system 141 receives representative input signals, a computing means under the control of a software program within the microprocessor control system 141 calculates the control pulses required by the power switching devices in order to supply a required electrical power to impart the required temperature change in the water flowing through the passage 112 so that heated water is emitted from the passage 112 at the desired temperature set by the user-controlled temperature device.

When a user sets the desired output water temperature using the set temperature device, the set value is captured by the microprocessor control system 141 and stored in a system memory until it is changed or reset. Preferably, a predetermined default value of 50 degrees Celsius is retained in the memory, and the set temperature device may provide a visual indication of the temperature set. The microprocessor control system 141 may have a preset maximum for the set temperature device which represents the maximum temperature value above which water may not be heated. Thus, the value of the set temperature device cannot be greater than the maximum set value. The system may be designed so that, if for any reason, the temperature sensed by the output temperature device 136 was greater than the set maximum temperature, the system would be immediately shut down and deactivated.

The microprocessor control system 141 repeatedly performs a series of checks to ensure that:

(a) the water temperature at the outlet does not exceed the maximum allowable temperature;

(b) leakage of current to earth has not exceeded a predetermined set value; and

(c) system current does not exceed a preset current limit of the system.

These checks are repeatedly performed while the unit is operational and if any of the checks reveals a breach of the controlling limits, the system is immediately deactivated. When the initial system check is satisfactorily completed, a calculation is performed to determine the required voltage that must be applied to the water flowing through the passage 112 in order to change its temperature by the desired amount. The calculated voltage is then applied to the pairs of electrodes 116, 117, 118 so as to quickly increase the water temperature as it flows through the passage 112.

As the water flowing through the passage 112 increases in temperature from the inlet end of the passage, the conductivity changes in response to increased temperature. The intermediate temperature measuring devices 138 and 139 and the output temperature measuring device 136 measure the incremental temperature increases in the three heating sections of the passage 112 containing the electrode sets 116, 117, 118, respectively. The voltage applied across the respective pairs of electrodes 116, 117, 118 can then be varied to take account of the changes in water conductivity to ensure that an even temperature rise occurs along the length of the passage 112, to maintain a substantially constant power input by each of the sets of electrodes 116, 117, 118 and to ensure greatest efficiency and stability in water heating between the input temperature measurement at 135 and the output temperature measurement at 136. The power supplied to the flowing water is changed by managing the control pulses supplied by the activated power switching devices Q1...Q9 commensurate with the power required. This serves to increase or decrease the power supplied by individual electrode pairs 116, 117, 118 to the water.

The system 100 repeatedly monitors the water for changes in conductivity by continuously polling the conductivity sensor 106, and also by referring to the current measuring devices 127, 128 and 129, and the temperature measurement devices 135, 136, 138 and 139. Any changes in the values for water conductivity within the system resulting from changes in water temperature increases, changes in water temperatures as detected along the length of the tube 112 or changes in the detected currents drawn by the water cause the computing means to calculate revised average voltage values to be applied across the electrode pairs. Changes in incoming water conductivity cause the microprocessor control system 141 to selectively activate changed combinations of electrode segments 116ai, 116aii, 116aiii, 117ai, 117aii, 117aiii, 118ai, 118aii, 118aii such that established maximum current values are not exceeded. Constant closed loop monitoring of such changes to the system current, individual electrode currents, electrode segment selection and water temperature causes recalculation of the voltage to be applied to the individual electrode segments to enable the system to supply relatively constant and stable power to the water flowing through the heating system 100. The changes in specific conductance of the fluid or water passing through the separate segmented electrode sections can be managed individually in this manner. Therefore the system is able to effectively control and manage the resulting specific conductance gradient across the whole system. This embodiment thus provides compensation for a change in the electrical conductivity of the fluid or water caused by varying temperatures and varying concentrations of dissolved chemicals and salts, and through the heating of the fluid or water, by altering the variable electrical voltage to accommodate for changes in specific conductance when increasing the fluid or water temperature by the desired amount.

Figure 2 is a perspective view of a segmented electrode 216a of a heating section 216. The segmented electrode 216a comprises three segments 216ai, 216aii and 216aiii. Appropriate electrical switching permits any combination of the three segments to be selectively activated at any given time. Electrode 216b is the common return of the electricity supply.

Figure 3 is a schematic of a fluid flow path 302 passing three heating sections 316, 317, 318. Each heating section comprises one electrode section segmented into three segments.

The teachings of US Patent No. 7,050,706, may be applied to control operation of aspects of the present apparatus and system.

The segmented electrodes of the present invention may be applied in a fluid heating device comprising a pre-heat reservoir in which fluid is heated to a desired pre-heat temperature and held in a reservoir, with segmented electrodes being used for heating of fluid in an outlet passage through which fluid flows from the reservoir upon demand. In this regard the contents of International Patent Publication No. WO 2008/116247.

It will be appreciated that any suitable number of electrode heating sections may be used in the performance of the present invention. Thus, while the embodiments described show three heating sections for heating the water flowing through passage 112, the number of heating sections in the passage may be altered in accordance with individual requirements or application specifics for fluid heating. If the number of electrodes is increased to, for example, six pairs, each individual pair may be individually controlled with regards to electrode voltage in the same way as is described in relation to the embodiments herein. Similarly, the number of segments into which a single electrode is segmented may be different to three. For example, segmentation of an electrode into four segments having active areas in a ratio of 1:2:4:8 provides 15 values of effective area which may be selected by the microprocessor control system 141.

Where water heating is concerned, it is to be appreciated that by utilising electrode pairs which cause current to flow through the water itself such that heat is generated from the resistivity of the water itself, the present invention obviates the need for conventional electrical resistance elements, thus ameliorating the problems associated with element scaling or furring.

It is further to be appreciated that the invention can be applied in applications that include, but are not limited to, domestic hot water systems and domestic near-boiling water dispensers. In relation to both such applications, which are often used for household hot water requirements, the invention can facilitate both energy and water savings. It is further to be appreciated that the provision of segmented electrodes comprising separately active segments permits installation of such a device in locations of widely differing fluid conductivity in which the microprocessor control system 141 can adapt device operation to the particular conductivity encountered without requiring laborious and expensive changes to physical device configuration. Additionally the system principles allow for ease of manufacture, ease of installation at point of use, pleasing aesthetics, and accommodates market established comfort factors. In describing the modes of operation of such applications in more detail, we first consider hot water systems.

A hot water system in accordance with one embodiment of the invention provides a through flow, instantaneous on-demand hot water system that delivers hot water at pre-settable or fixed temperature to one or more of kitchen, bathroom and laundry in a domestic setting. The output temperature can be accurately controlled and kept stable despite adverse water supply conditions that may prevail. The electrical power requirements for this type of application usually range between 3.0kW and 33kW and will require either a single or multi-phase alternating current electrical power source. The electrical power source requirements can vary depending on the specific nature of the application. The system is designed to deliver hot water to the user at flow rates that typically vary between 0.5 litres/min and 15litres/min. Again this depends on the specific application. Output water temperatures can be fixed or made settable between 2 degC and 60 degC, which again depend on the application and domestic regulations. The temperature increment capability will nominally be 50degC at 10litres/min, but again depends on the application.

We now turn to a boiling water dispenser in accordance with another embodiment of the present invention. The boiling water dispenser in this embodiment of the invention provides a through flow, instantaneous boiling water dispenser designed to deliver hot water at a fixed output temperature, up to a maximum of 98degC. This unit will most often be installed at the point of use in a kitchen-type environment. The output temperature is accurately controlled and kept stable despite adverse water supply conditions that may prevail. The electrical power requirements for this type of application usually range between 1.2kW and 6kW. The flow rate of this dispenser is fixed. This would nominally be fixed at a rate of between 0.5litres/min or 1.2litres/min, but again this depends on the application. The power requirement is dependent on the application requirements.

We now turn to a through flow boiling water dispenser in accordance with a further embodiment of the present invention. If such a system is required to deliver boiling water instantaneously and continuously at between 0.5litres/min and 1.2ltrs/min without storage or preheating, then typically 6.6kW of electrical power is required and a commensurate electrical supply circuit needs to be installed. This embodiment is capable of delivering near boiling water practically continuously without interruption for as long as is required. Extremely low standby losses of 2W per day will be experienced. Previously, delivery of continuous instantaneous, on-demand boiling water could not be accommodated by available, competitive instantaneous hot water system technology due to the requirement for high line pressures that necessarily result in flow rates of greater than 2litres/min. It is not practical to use flow rates much greater than 1.2litres/min for boiling water dispensers.

In another embodiment of the present invention, a two stage boiling water dispenser is provided. If normal single phase power outlets are to be used, the power requirement can be kept to between 1.8kW and 2.5kW which is acceptable for standard domestic power points, and does not require additional or special power circuits. This embodiment requires a two stage boiling water dispenser system that includes a water storage component as well as a dynamic through flow component. In this regard, water is first heated to 65degC in a storage system designed to hold nominally 1.8litres to 2.0litres of water. Once heated to 65degC, the boiling water dispenser becomes operable, at which time when turned on the water at 65degC is delivered through the dynamic section to the delivery outlet. This dynamic sector heats the water flowing at 0.8litres/min to 1.2liters/min on demand by an additional 30degC, to an output temperature of 95degC.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative.
The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

CLAIMS:

1. A method for heating fluid, the method comprising:

passing the fluid along a flow path from an inlet to an outlet, the flow path comprising at least first and second heating sections positioned along the flow path such that fluid passing the first heating section subsequently passes the second heating section, each heating section comprising at least one pair of electrodes between which an electric current is passed through the fluid to resistively heat the fluid during its passage along the flow path, and wherein at least one of said heating sections comprises at least one segmented electrode, the segmented electrode comprising a plurality of electrically separable segments allowing an effective active area of the segmented electrode to be controlled by selectively activating the segments such that upon application of a voltage to the activated electrode segment(s), current drawn will depend upon the effective active area;

measuring fluid conductivity at the inlet;

determining from measured fluid conductivity a required voltage and current to be delivered to the fluid by the first heating section to raise the fluid temperature by a first desired amount;

determining an altered fluid conductivity resulting from operation of the first heating section;

determining from the altered fluid conductivity a required voltage and current to be delivered to the fluid by the second heating section to raise the fluid temperature by a second desired amount; and

activating segments of the segmented electrode in a manner to effect delivery of desired current and voltage by the segmented electrode.

2. The method of claim 1, wherein variations in fluid conductivity are substantially continually accommodated in response to measurements of incoming fluid conductivity.

3. The method of claim 1, wherein fluid conductivity is determined by reference to the current drawn upon application of a voltage across the one or more pairs of electrodes of the one or more heating sections.

4. The method of any one of claims 1 to 3, further comprising using the measured conductivity value to initially select an established, commensurate combination of electrode segments before allowing the system to operate in order to prevent variations in fluid conductivity from causing the peak current to exceed a rated value.

5. The method of any one of claims 1 to 4, further comprising deactivating the electrodes if the measured fluid conductivity falls outside a predetermined range of acceptable fluid conductivity.

6. The method of any one of claims 1 to 5, further comprising measuring a fluid flow rate to assist in determination of appropriate current, voltage and electrode segment activation under varying fluid flow rates.

7. The method of any one of claims 1 to 6, further comprising measuring fluid temperature at the outlet to permit feedback control of the fluid heating.

8. The method of any one of claims 1 to 7, further comprising measuring the temperature of the fluid between the first and second heating sections and controlling power to the first and second heating sections in accordance with the measured temperatures and a desired fluid temperature increase in each respective heating section.

9. The method of any one of claims 1 to 8, wherein the fluid flow path comprises three or more heating sections, each section having the inlet and the outlet, the sections being connected in series, the method further comprising the control means initially selecting electrode segments in accordance with the measured incoming water conductivity and controlling power to an electrode pair of each section in accordance with measured inlet and outlet temperatures of each section and a predetermined desired temperature difference for each section.

10. An apparatus for heating fluid, the apparatus comprising:

a fluid flow path from an inlet to an outlet;

at least first and second heating sections positioned along the flow path such that fluid passing the first heating section subsequently passes the second heating section,

each heating section comprising at least one pair of electrodes between which an electric current is passed through the fluid to resistively heat the fluid during its passage along the flow path, and wherein at least one of said heating sections comprises at least one segmented electrode, the segmented electrode comprising a plurality of electrically separable segments allowing an effective active area of the segmented electrode to be controlled by selectively activating the segments such that upon application of a voltage to the segmented electrode current drawn will depend upon the effective active area;

a conductivity sensor for measuring fluid conductivity at the inlet; and

a controller for determining from measured fluid conductivity a required voltage and current to be delivered to the fluid by the first heating section to raise the fluid temperature by a first desired amount, for determining an altered fluid conductivity resulting from operation of the first heating section, for determining from the altered fluid conductivity a required voltage and current to be delivered to the fluid by the second heating section to raise the fluid temperature by a second desired amount, and for activating segments of the segmented electrode in a manner to effect delivery of desired current and voltage by the segmented electrode.

11. The apparatus of claim 10, wherein each heating section comprises a segmented electrode.

12. The apparatus of claim 10 or 11, wherein each segmented electrode is divided into segments of varying size, to permit combinations of segments to be selected to provide an increased accuracy of selection of desired effective area.

13. The apparatus of claim 12, wherein the segmented electrode is divided into n segments having relative effective areas in a ratio of 1:2: ... :2(n-1).

14. The apparatus of any one of claims 10 to 13, wherein each electrode segment of the segmented electrode extends substantially perpendicularly to a direction of fluid flow, so as to subject fluid across substantially the entire fluid flow path to resistive heating.

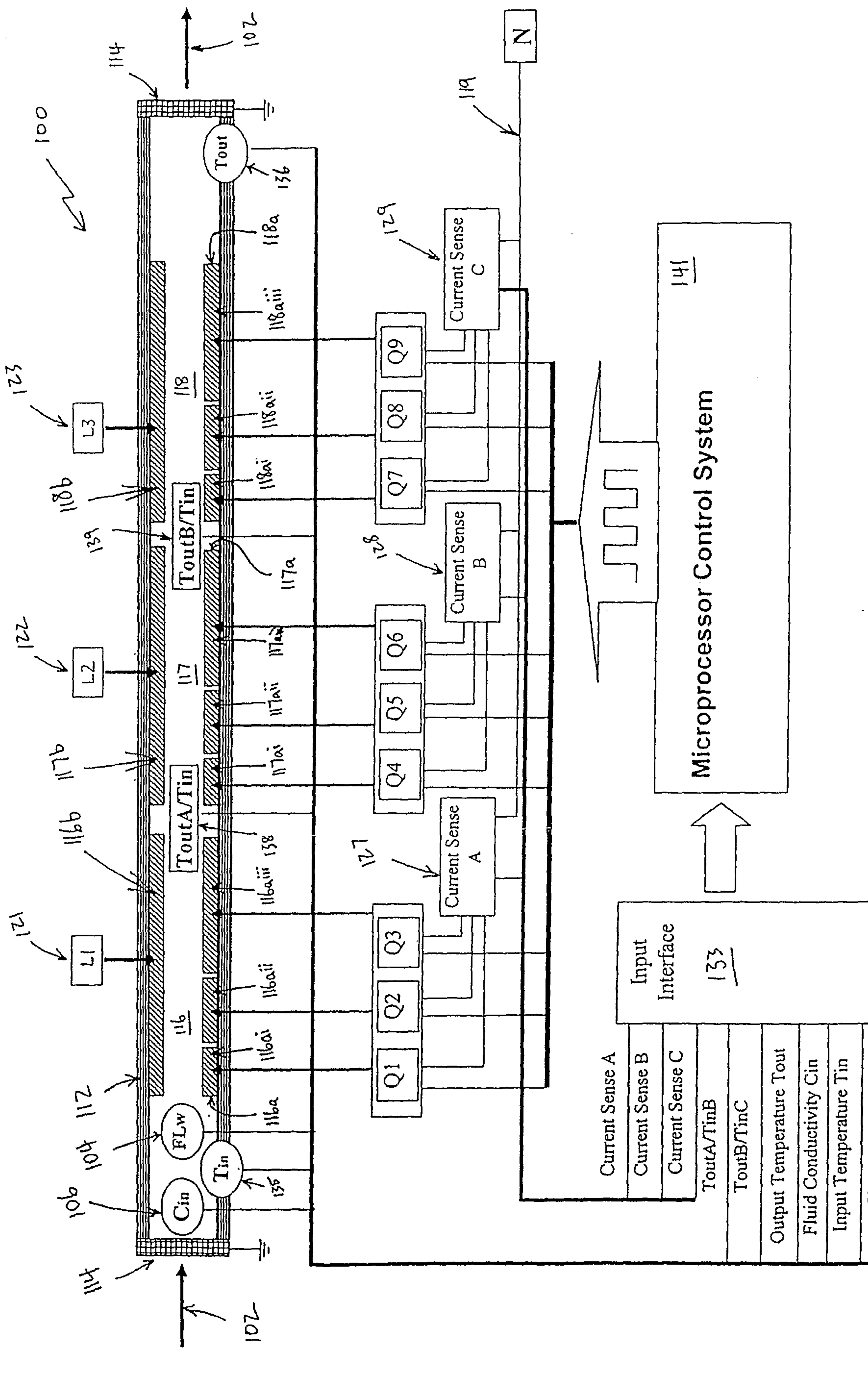
15. The apparatus of any one of claims 10 to 14, further comprising flow rate measuring means for measuring a fluid flow rate to assist in determination of appropriate current, voltage and electrode segment activation under varying fluid flow rates.

16. The apparatus of any one of claims 10 to 15, further comprising outlet fluid temperature measuring means for measuring fluid temperature at the outlet to permit feedback control of the fluid heating.

17. The apparatus of any one of claims 10 to 16, further comprising fluid temperature measuring means for measuring the temperature of the fluid between the first and second heating sections and controlling power to the first and second heating sections in accordance with the measured temperatures and a desired fluid temperature increase in each respective heating section.

18. The apparatus of any one of claims 10 to 17, wherein the fluid flow path comprises three or more heating sections, each section having the inlet and the outlet, the sections being connected in series.

1/3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116b
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117b
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118a
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118aii
118aiii
118b
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133
135
136
138
139
141
L1
L2
L3
N
Cin
FLw
Tin
Tout
ToutA/Tin
ToutB/Tin
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Current Sense A
Current Sense B
Current Sense C
Microprocessor Control System
Input Interface
Current Sense A
Current Sense B
Current Sense C
ToutA/TinB
ToutB/TinC
Output Temperature Tout
Fluid Conductivity Cin
Input Temperature Tin
Flow Rate FLw

Figure 1

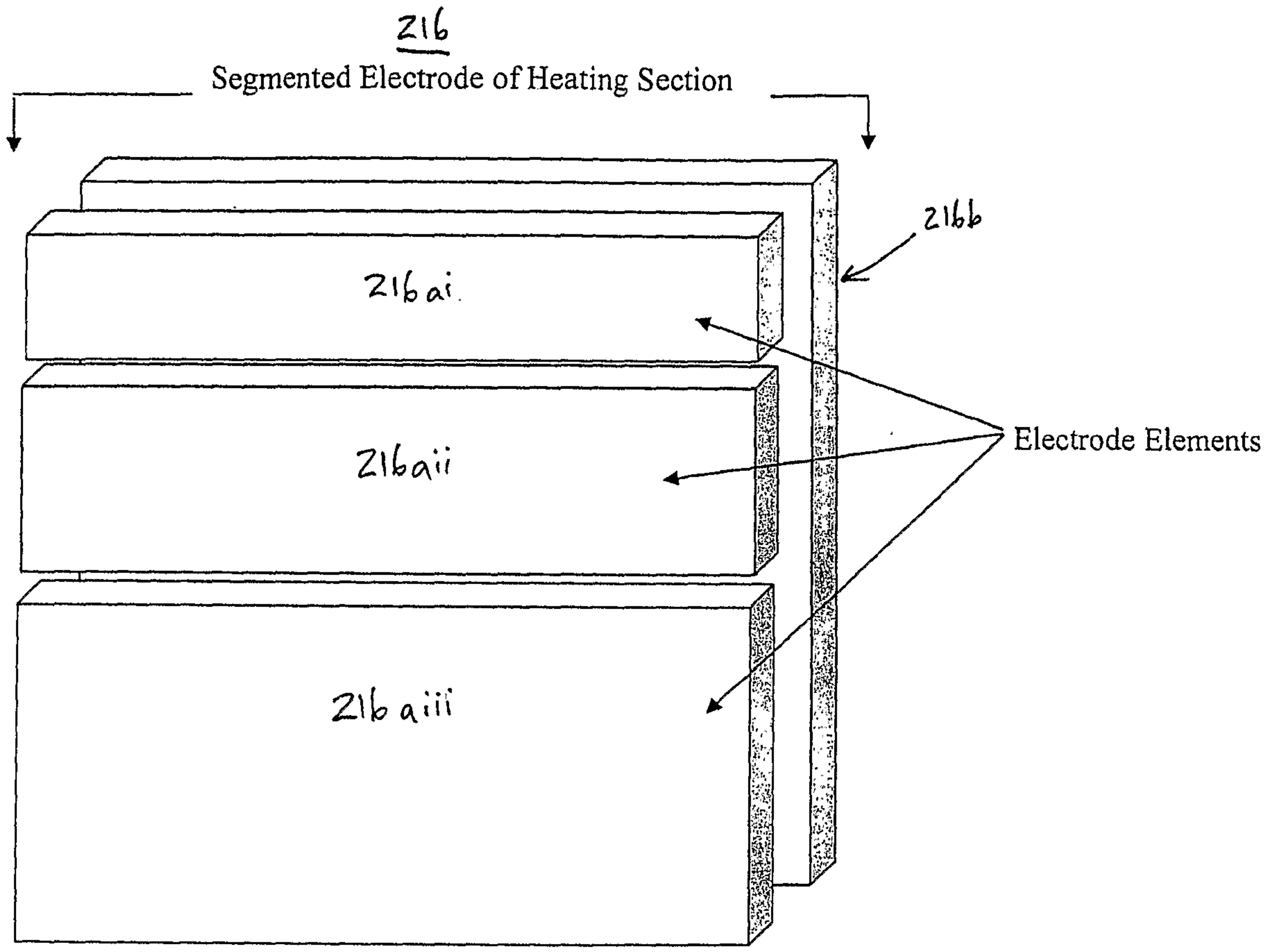

216
Segmented Electrode of Heating Section
216b
216ai
216aii
216aiii
Electrode Elements

Figure 2

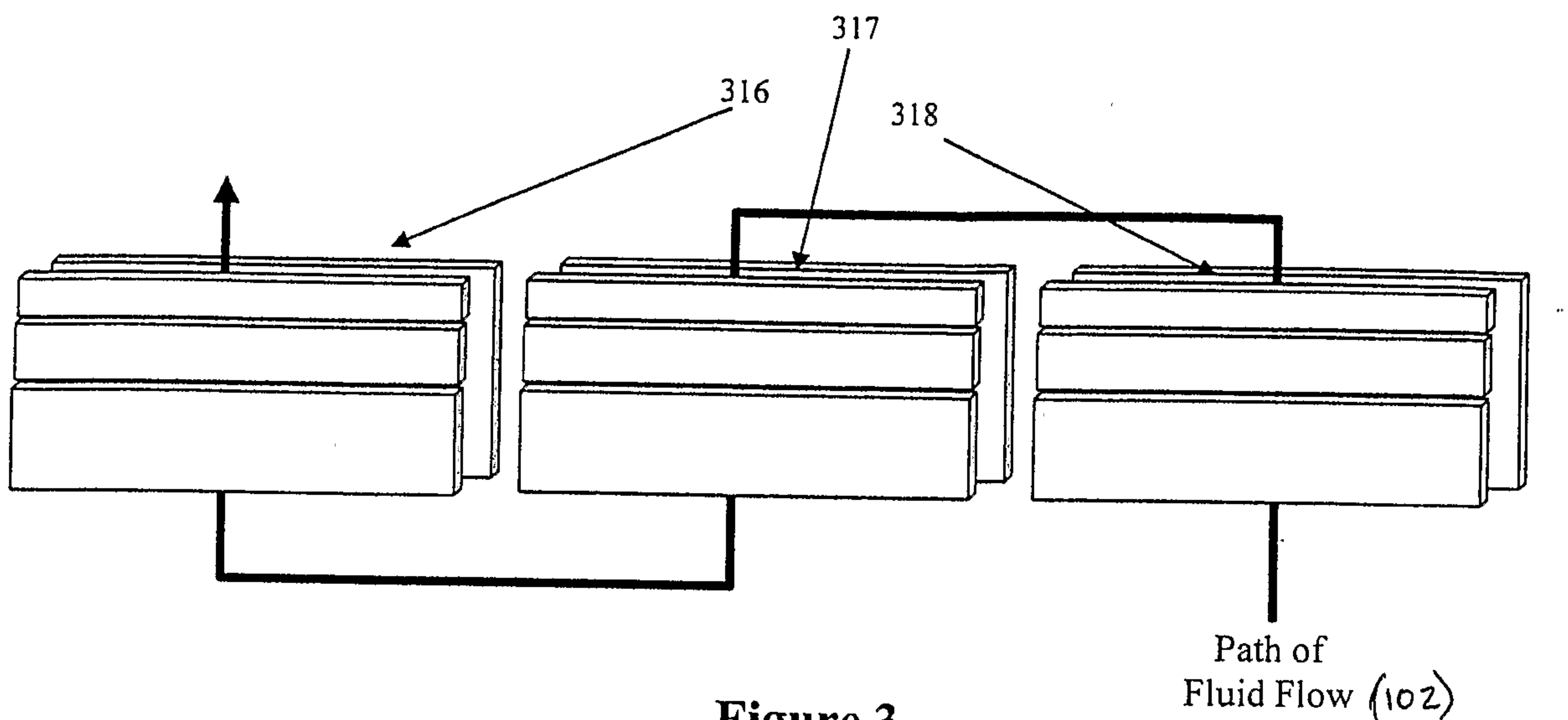
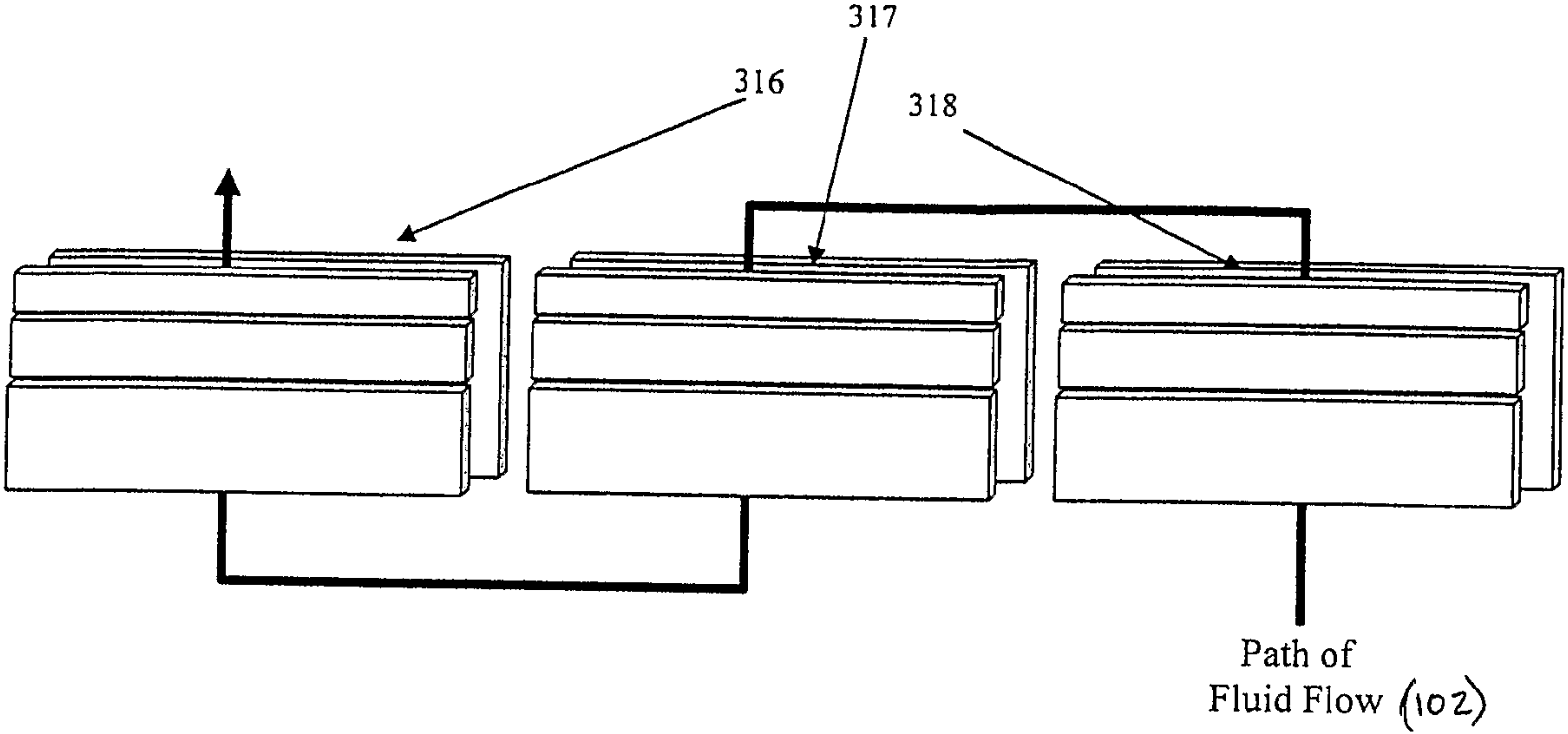


Figure 3



317
316
318
Path of
Fluid Flow (102)