# United States Patent

[11] 3,590,215

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[54] **CLINICAL FLUID WARMER**
**7 Claims, 5 Drawing Figs.**

[52] U.S. Cl. 219/298, 128/214, 128/399, 165/46, 219/299, 219/308, 219/330, 219/525
[51] Int. Cl. A61j 1/00, F24h 1/20, H05b 1/02
[50] Field of Search 219/296—299, 301—309, 311, 310, 313, 327, 328, 521, 524, 525; 128/272, 214, 399, 400; 165/46, 171, 80, 74, 86; 222/146, 146 HE

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**ABSTRACT:** A dry heat clinical blood warmer comprising first and second heater plates, pivotally mounted relative to each other; a thin, flat, channeled sac, having an inlet and an outlet spaced from each other, is mounted between the plates, the sac contacting both plates when the plates are closed. The electrical heater elements for the plates are effectively tapered, by positioning or by power relationships, from inlet end to outlet end, in proportion to the diminishing rate of heat absorption of blood or other fluid flowing through the sac.

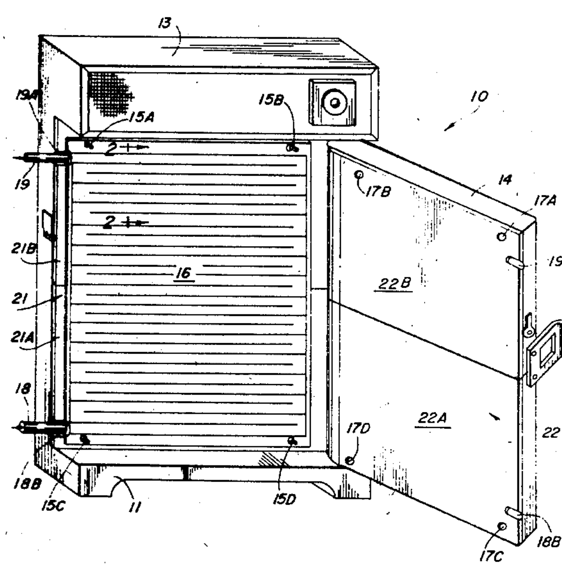

FIG. 1

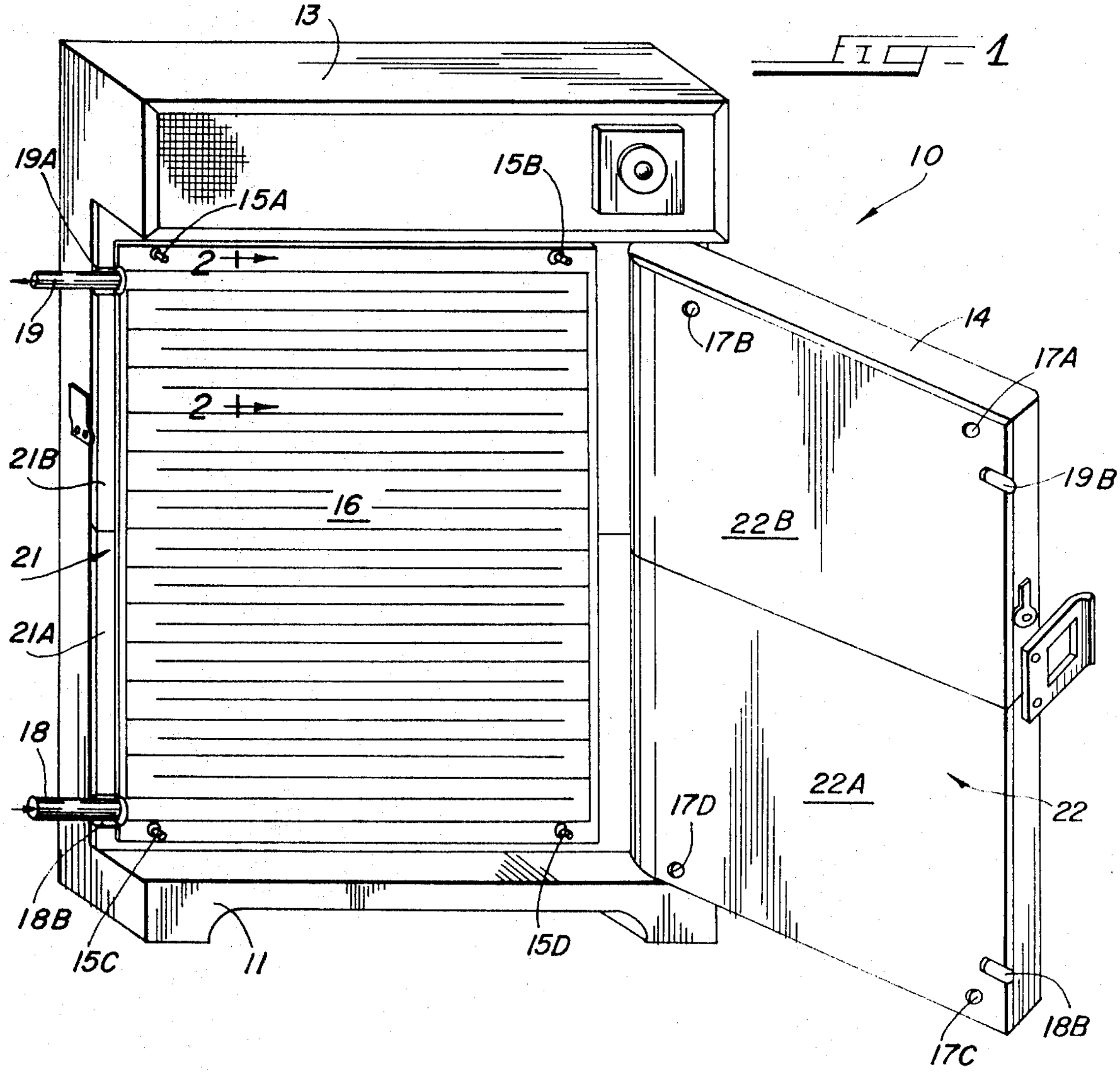


FIG. 2

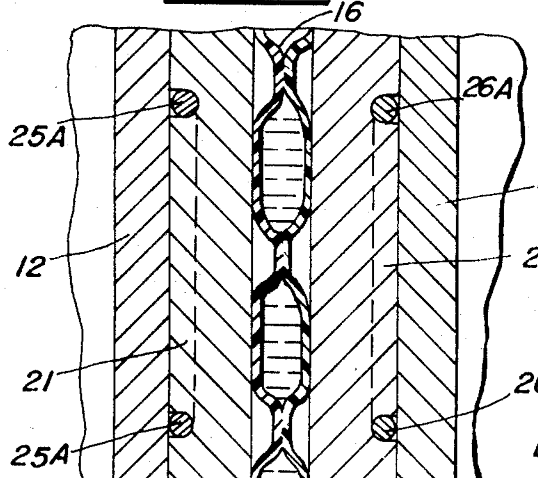


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FIG. 3

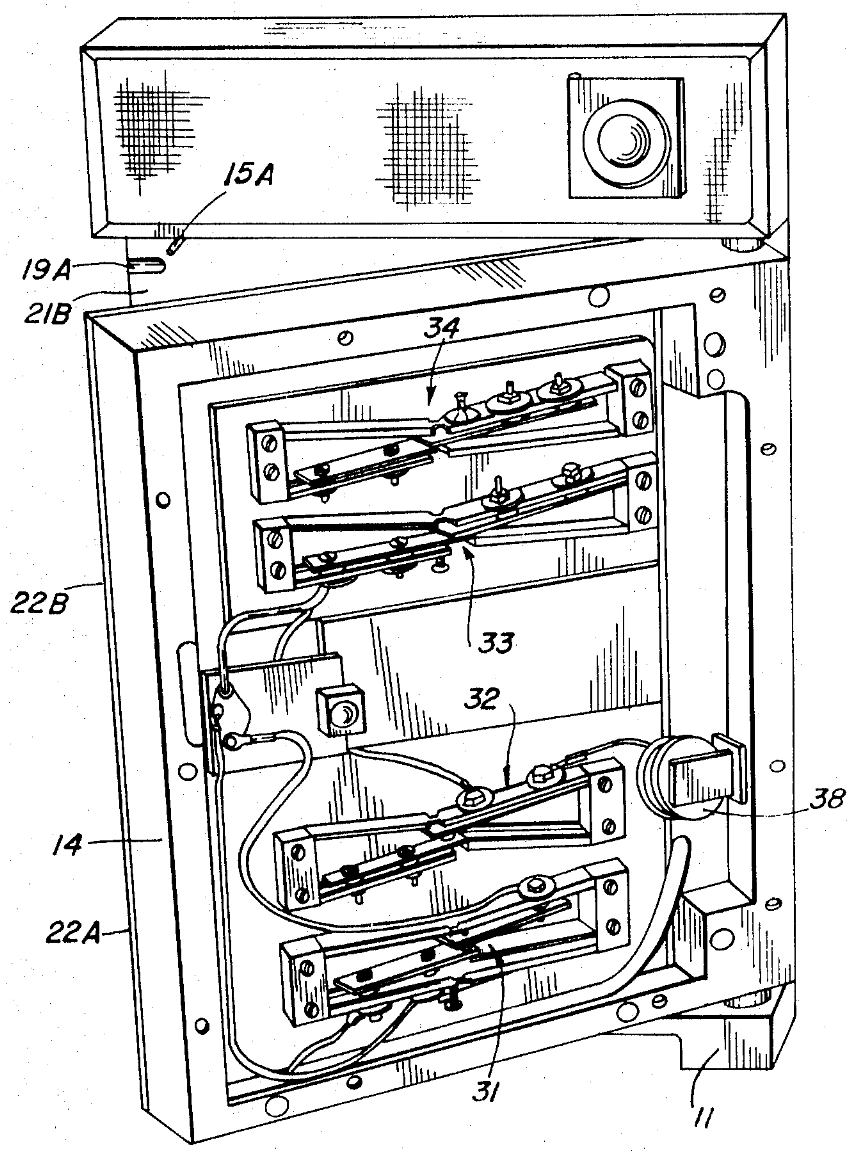


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FIG. 4

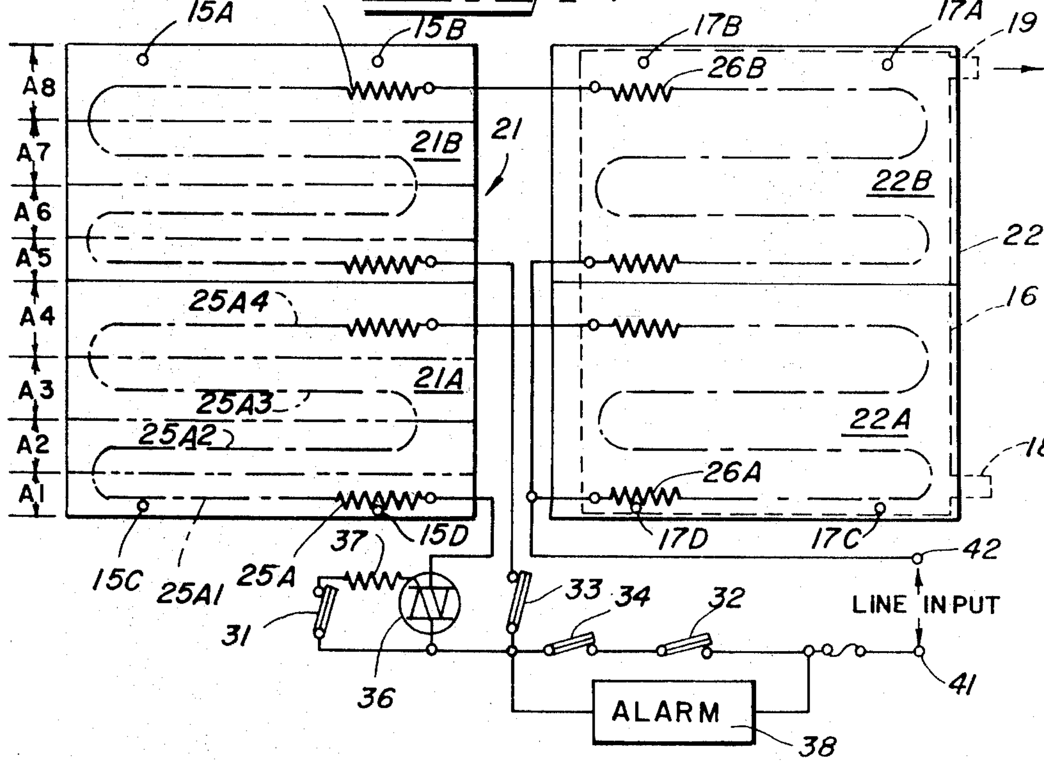
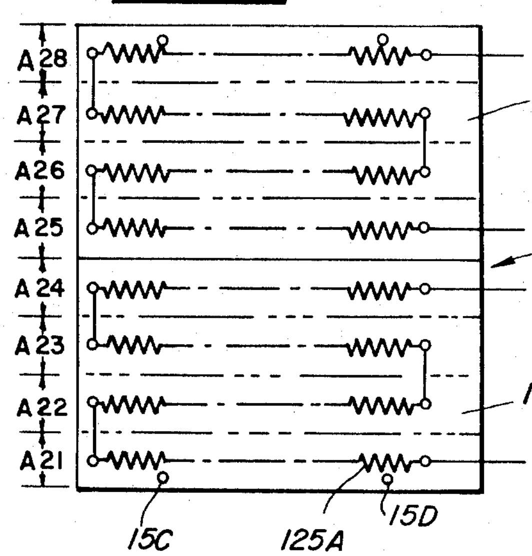



FIG. 5

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# CLINICAL FLUID WARMER

## CROSS-REFERENCE TO RELATED APPLICATION

This invention is an improvement upon the clinical fluid warmer disclosed and claimed in the copending application of Germain G. Pins, Ser. No. 589,262, filed Oct. 25, 1966 and assigned to the same assignee as the present, now U.S. Pat. No. 3,475,590, issued Oct. 28, 1969 invention

## BACKGROUND OF THE INVENTION

Blood is ordinarily refrigerated and stored at temperatures of the order of 4° C. For utilization, it must be warmed to approximate body temperature of 37° C. For a given surgical procedure, it is customary practice to warm enough blood to meet all anticipated transfusion needs, frequently resulting in a substantial loss when some of the anticipated needs fail to occur. The excess blood cannot be refrigerated a second time and must be destroyed.

Continuous blood heating devices have been proposed, using a liquid heating bath and a heat transfer coil immersed in the bath, the blood being heated by passage through the coil. Devices of this kind, however, tend to produce substantial overheating or underheating of the blood depending upon the rate of flow of the blood. Ideally, a blood warmer should be able to supply blood for use in a quite restricted temperature range despite large variations in flow rate.

The blood warmer of the aforesaid Pins U.S. Pat. No. 3,475,590 affords a controlled temperature output for the blood over a practical range of flow rates from 0 to 150 cubic centimeters per minute. That is, the Pins blood warmer assures a supply of blood at a temperature within an acceptable rang for transfusion purposes, starting with blood refrigerated to 4° C. or even lower, even though the flow rate may be changed from a maximum of 150 cc. per minute to a complete stop at any time during the transfusion procedure. However, the Pins device does present some difficulties with respect of cleaning and accessibility and is susceptible of some improvement with respect to the precise control of the blood temperature.

## SUMMARY OF THE INVENTION

It is a principal object of the present invention, therefore, to provide a new and improved dry heat clinical blood warmer that utilizes the structural features and operating attributes of the Pins blood warmer to the fullest extent, but provides much greater convenience and accessibility in changing from one blood supply to another or from one patient to another.

Another object of the invention is to provide a new and improved dry heat clinical blood warmer which is readily and conveniently cleaned, even in those instances in which an accident may occur and some spillage of blood or other transfusion fluid may take place.

Another principal object of the invention is to afford a new an improved dry heat clinical blood warmer in which thermal control is made more effective by precise proportioning of the electrical heater elements in accordance with the diminishing rate of heat absorption of the blood or other fluid flowing through the heater.

Accordingly, the invention relates to a dry heat clinical fluid warmer for use in warming refrigerated blood and other fluids to a safe, usable transfusion temperature, at any flow rate from zero to a given maximum rate. The warmer of the invention comprises first and second thermally conductive heater plates and means for mounting those plates for pivotal movement between a closed position in which the plates are in closely spaced parallel relation and an open position in which the plates are rather widely spaced from each other. The warmer further comprises support means for removably supporting a thin, flat, channelled fluid-conducting sac on one of e heater plates, the sac having inlet and outlet openings at opposite ends thereof. When the heater plates are in closed position and the sac is filled with fluid, the opposed sides of the sac contact the first and second heater plates, respectively. First and second heating elements are provided for the first and second heater plates, respectively. Each heating element is tapered from the inlet end to the outlet end so that the heat output diminishes in proportion to the diminishing rate of heat absorption of fluid moving from the sac inlet to the sac outlet. Precision thermal control means are provided for controlling the operation of the heating elements in accordance with the temperature of one of the heater plates.

Other and further objects of the present invention will be apparent from the following description and claims and are illustrated in the accompany drawings which, by way of illustration, show preferred embodiments of the present invention and the principles thereof and what is now considered to be the best mode contemplated for applying these principles. Other embodiments of the invention embodying the same or equivalent principles may be made as desired by those skilled in the art without departing from the present invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front perspective view of a clinical fluid warmer constructed in accordance with one embodiment of the present invention;

FIG. 2 is a detail sectional view of a part of the fluid warmer of FIG. 1 illustrating the engagement of the heater plates with the sac that carries fluid through the warmer;

FIG. 3 is a perspective view of the clinical fluid warmer of FIG. 1 with the door nearly closed and with a door cover removed to show the thermostatic controls;

FIG. 4 is a schematic diagram of the heating elements and electrical controls for the clinical fluid warmer of FIGS. 1—3; and

FIG. 5 is a schematic illustration of the heating elements for a different embodiment of the invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1—4 illustrate a dry heat clinical fluid warmer 10, for use in warming refrigerated blood and other fluids to a safe usable transfusion temperature, constituting a first embodiment of the present invention. The clinical fluid warmer 10 comprises a base 11 and an upwardly extending stationary frame 12. Base 11 projects forwardly of the frame 12 and, at the upper end of the frame, there is a forwardly projecting housing 13.

A first thermally conductive heater plate 21 is fixedly mounted on frame 12. Heater plate 21 is formed in two sections, a lower section 21A and an upper section 21B. A second thermally conductive heater plate 22 is included in fluid warmer 10. Like heater plate 21, plate 22 is constructed in two sections, a lower section 22A and an upper section 22B. Heater plate 22 is mounted upon door 14 that is pivotally mounted upon the base and frame 11—13 of the fluid warmer device. Thus, heater plates 21 and 22 are pivotally movable, relative to each other, between an open position (FIG. 1) and a closed position; in the closed position the two heater plates are disposed in closely spaced parallel relation to each other (FIG. 2).

Warmer 10 further comprises support means for removably supporting a thin, flat, channelled fluid-conducting sac 16 in predetermined position upon heater plat 21. This support means comprises four pins 15A, 15B, 15C and 15D mounted on frame 12 and positioned to project through four corresponding apertures in sac 16. Pins 15A—15D are aligned with four corresponding apertures 17A—17D in heater plate 22. The support means for the fluid-conducting sac 16 further comprises individual slots 18A and 18B in heater plates 21A and 22A, respectively, for receiving an inlet opening tube 18 that is a part of sac 16. Corresponding slots 19A and 19B in heater plate sections 21B and 22B, respectively, receive the outlet tube 19 of the sac.

As can be seen from FIG. 1, when door 14 is open heater plate 22 is disposed at a relatively wide angle with respect to heater plate 21. Complete accessibility is thus provided for mounting or demounting the plastic fluid-conducting sac 16 in device 10. But when door 14 is closed, the two heater plates 21 and 22 are disposed in closely aligned parallel spaced relation to each other, as shown by the detail sectional view of FIG. 2. Thus, when door 14 is closed and the heater plates are in their closed positions, relative to each other, the opposite sides of the channelled sac 16 contact heater plates 21 and 22 respectively. This provides for a rapid and efficient heat transfer from the heater plates to the fluid in sac 16.

Heater plates 21 and 22 are each provided with electrical heating elements. The positioning and alignment of the heating elements for warmer 10, in relation to the heater plates, is best illustrated in FIG. 4. As shown therein, heater plate sections 21A and 21B are provided with individual electrical resistance heaters 25A and 25B, respectively. The heating elements 25A and 25B are each effectively tapered from the bottom of the heating element to the top of the heating element so that the heat output diminishes in an upward direction across the face of heater plate 21. MOre specifically, the heating elements are effectively tapered so that the heat output diminishes gradually from that portion of the heater plate that is adjacent to the inlet end 18 of the sac 16 to the outlet end 19 of the sac, in proportioned to the diminishing rate of heat absorption of fluid moving through the sac from its inlet to its outlet.

To understand the requirement for tapering of the heating elements 25A and 25B, consideration may be given to the thermal changes of fluid flowing through the channelled sac 16. The flood or other lid gradually increases in temperature as it traverses the sac from the bottom inlet 18 to the top outlet 19. The rate of heat absorption of the fluid is proportional to the temperature differential between the blood and the heater plates 21, 22. The heater plates are of high thermal conductivity (relatively heavy cast aluminum is preferred) and hence generally uniform in temperature. Consequently, the fluid absorbs less heat near the outlet end of the sac 16 than near the inlet end because the temperature difference is much smaller at the outlet end of the sac.

The second heater plate 22, comprising sections 22A and 22B, includes two sectional heating elements 26A and 26B. EAch of the heating elements 25A, 25B, 26A and 26B is of sinuous configuration and each includes four main horizontally disposed segments. For practical purposes, the end connections between the horizontal segments can be disregarded. Furthermore, the rate of heat output for heating element 25A is constant throughout its length. But the four horizontal segments of heater element 25A are not equally spaced with respect to the vertical height of heater plate section 21A.

Thus the first or lower horizontal segment 25A1 of heating element 25A is centered in a relatively small area A1 of heater plate section 21A. Note that this area A1 is aligned with the inlet 18. The next horizontal segment 25A2 of the same heating element is centered in a somewhat wider segmental area A2 of the heater plate. the next segmental area, in which the heating element segment 25A3 is centered, is still wider, and the widest of the segmental areas of the heater plate 25A is the uppermost area A4 containing the last heating element segment 25A4. The same distribution pattern is utilized for each of the heating element sections 25B, 26A and 26B.

The electrical control for device 10 is shown in FIGS. 3 and 4. It comprises four thermostats 31, 32 33 and 34 mounted in cover 14 on the rear surfaces of heater plate 21, as shown in FIG. 3. Thermostat 31 is a principal control thermostat for the electrical heating elements 25A and 26A. Thermostat 33 is a main control thermostat for the heating elements 25B and 26B. Thermostats 32 and 34 are limiting thermostats for controlling an alarm system.

As shown in the schematic diagram of FIG. 4, the heating elements of device 10 are energized for a conventional AC supply having terminals 41 and 42. One line terminal 41 is connected through thermostats 32 and 34, in series, and through thermostat 32 to the input terminal of heating element secton 25B. The other terminal of heating element section 25B is connected across to the corresponding heating element section 26B in the other heater plate and the latter is returned to the other line terminal 42.

The control circuit for the lower heating element sections 25A and 26A is similar but is made specifically different to handle higher currents. Thus, the energizing circuit for heating element sections 25A and 26A, beginning at line terminal 41, again extends through the two series-connected thermostats 32 and 34. From thermostat 34, the circuit extends to the input electrode of a triac 36, the output electrode of the triac being connected to heating element section 25A, which is connected in series with heating element section 26A back to line terminal 42. The control thermostat at 31 is connected, in series with a current-limiting resistor 37, between the input electrode of triac 36 and the gate electrode of the triac.

In normal operation, thermostat 33, which is mounted on the upper heated plate section 21B (FIG. 3) directly controls the energization and deenergization of the two series-connected upper heating element sections 25B and 26B. Thermostat 34 is also mounted upon the upper heater plate section 21B, but does not serve a primary control function for the upper heating elements. It serves only as an limit control to actuate an alarm 38 in the event of some failure on the part of thermostat 33 or some other malfunction of the warmer that leads to substantial overheating of the plate section 21B.

Similarly, thermostat 32 does not perform a major control function with respect to either heating element section 25A or section 26A, although it is mounted on heater plate section 21A. Like thermostat 34, thermostat 32 is set for a temperature slightly above the desired operating temperature for the heater plated and functions only in the event that the main control for heating element sections 25A and 26A 31 and triac 36) fails to perform properly. The alarm 38, which may comprise an audible, visual or other type of alarm, is connected in parallel with thermostats 32 and 34. The alarm being normally shunted by the two thermostats, does not operate unless one of the two thermostats is heated beyond its setting, opening and allowing energization of the alarm.

From the foregoing description and with particular reference to FIG. 4, it is seen that warmer 10 provides two pairs of heater plate sections, each controlled by a single thermostat mounted don one of the plate sections. Thus, the input to the entire heating surface of each pair of heater plate sections is controlled in accordance with the conditions of thermal equilibrium at only one point. If the heat supply preceeds or falls below the rate of heat absorption at some other point, on either pair of heater plate sections, an undesirable temperature variation can result.

The design of the heating elements cannot be optimized for more than one flow rate unless the heater plates are subdivided into minute incremental areas, each with its own heating element and control. But good results can be obtained with two equalized heating areas, separately controlled as in device 10. That is, the heating elements of the two sections of the heater plated can be so proportioned that the heat supply equal the heat demand over each area at some maximum rate of flow. A maximum flow rate is selected as the control criterion because the danger of shock to a patient, from blood transfused below body temperature, increases as the flow rate increases and because the temperature increase in the fluid processed by the warmer decreases as the flow rate increases. That is, by optimizing the "tapering" of the heating elements for the maximum permissible flow rate of the fluid warmer, the temperature increase in the blood at that rate is placed under maximum control.

In warmer 10, in any comparable heat exchanger in which a liquid medium is heated in a thin thermally conductive bag sandwiched between relatively closely spaced heating plates, the eat differential can be represented by the relationship:

(1) $dH=KAP(To-T)dt/D$

in which

$dH$ = heat differential

$T_o$ = temperature of the plates, in degrees, above initial liquid temperature

$T$ T33 temperature of liquid at given time

$dt$ = time differential

$D$ = thickness of sac

$K$ = thermal conductivity of sac

$A$ = contact area of one plate

$P$ = effective contact area to actual plate area

The increase in temperature $dT$ is an incremental time $dt$ is:

(2) $dT=d_H/V$

in which $dT$ = temperature increase in time $dt$

$V$ = fluid volume in sac.

As a working approximation, it may be assumed that the specific gravity of the fluid being heated is unity and that the specific heat is also unity. All units are assumed to be in the cgs system. With these assumptions, and on the further consideration that the volume of the sac **16** is proportional to its surface area, the foregoing expressions (1) and (2) can be developed to afford a fundamental heat exchange equation for warmer **10**, at a maximum fluid flow rate S, as follows:

$$(3)\qquad T=T_0\left[1-e^{\frac{-KAP}{DS}}\right]$$

In a typical design, it may be assumed that the total surface are of sac **16** is 400 sq. cm. and that the effective sac area is a total of 200 sq. cm. for each of the heater plates, the reduction being due to the channelled construction of the sac (see FIG. 2). For a typical plastic material suitable for sac **16**, the thermal conductivity may be taken as 0.00035, the thickness of the sac may be assumed to be 0.0254 cm. and the maximum rate of flow may be taken as 150 cc. per minute 2.5 cc. per second. On this basis, and starting with blood refrigerated to a temperature of 4° C. to be transfused at a temperature of 37° C., the temperature rise $T$ for the lower heater plate sections **21A** and **22A**, as derived from equation (3), is 22° C. One-fourth of this total temperature rise is to be contributed by each of the segmental areas **A1** through **A4**. If equation (3) is solved for the area $A$, it results in the expression

$$(4)\qquad A=\frac{DS}{2PK}\ln\left[\frac{T_0}{T_0-T}\right]$$

and the individual areas **A1** through **A4** may be calculated in accordance with the series relationship:

$$(5)\qquad A_1=\frac{DS}{2PK}\ln\left[\frac{T_0}{T_0-T'}\right]$$

$$A_1+A_2=\frac{DS}{2PK}\ln\left[\frac{T_0}{T_0-2T'}\right]$$

$$A_1+A_2\ \ldots\ +A_n=\frac{DS}{2PK}\ln\left[\frac{T_0}{T_0-nT'}\right]$$

in which $T'$ = fluid temperature rise per segment

$A_1 \ldots A_n$ = segment areas, inlet end to outlet end.

For the construction specifically illustrated in FIG. **1—4** with the parameters assumed above, the calculations for the segmental areas **A1—A4** are as follows:

$A_1$=182 $1n$ 33/33—5.533.2 sq. cm.

$A_1+_2$=182 $1n$33/33—11=73.7 sq. cm.

$A_1+A_2+A_3$=126 sq. cm.

$A_1+_2+A_3+A_4$=200 sq. cm.

and the actual areas are:

**A1**=33.2 sq. cm

**A2**=40.5 sq. cm.

**A3**=52.3 sq. cm.

**A4**=74 sq. cm.

With similar assumptions, and calculations on the same basis, the incremental areas for the upper heater plate sections, segmental areas **A5** through **A8**, can be shown to be

**A5**=33.2 sq. cm.

**A6**=40.5 sq. cm.

**A7**=52.3 sq. cm.

**A8**=74 sq. cm.

Even though segmental areas **A5** through **A8** are equal to areas **A1** through **A4**, respectively, heating element **25B** is not the same as heating element **25A** because it is required to produce only one-third of the heat output of heating element **25A**. That is, heating element **25B** contributes only one-third of the total temperature rise that is contributed by heating element **25A**.

At the maximum flow rate for fluid through warmer device **10**, the two lower heating elements **25A** and **26A** require a total heat output of approximately 230 watts. However, it is necessary to provide for peripheral heat losses and to compensate for possible drops in line voltage. In a practical design, a total capacity of 450 watts for the two heating elements **25A** and **26A** is adequate. The upper two heating elements **25B** and **26B** need only a third of this heating capacity and may total 150 watts. These heat capacities are divided equally between the two heating element sections in each pair.

The division of heater plate section **21A** into the four segmental areas **A1** through **A4** is a matter of practical design considerations and is not critical to the present invention. That is, the total number of transverse legs or segments to the heating element section **25A** can be varied. For example, in a given construction it may be desirable to use six transverse segments or legs for the heater element, which would produce six segmental areas of progressively increasing size, form bottom to top of the heater plate section. Calculated as described above, the segmental areas would be as follows:

$A11$=21.5 sq. cm.

$A12$=24.2 sq. cm.

$A13$=28.0 sq. cm.

$A14$=33.3 sq. cm.

$A15$=40.8 sq. cm.

$A16$=52.2 sq. cm.

The heating elements **25A**, **25B**, **26A** and **26B**, constructed as described above, are each effectively tapered from the lower or inlet end to the upper or outlet end so that the heat output of the two heater plates diminishes gradually, form inlet end to outlet end, in proportion to the diminishing rate of heat absorption of fluid moving through sac **16**. This is accomplished by the thermal control, and particularly thermostats **31** and **33**, even through the thermostats control operation of the heating elements in accordance with the temperature of only one heater plate. Relatively precise control is possible because the equilibrium conditions at corresponding positions on the front and back heater plates are essentially identical. Moreover, since sac **16** is filled with a liquid medium, there is effective heat conduction, through the sac and the liquid, between the front and back heater plates.

The same basic operating effect, with the heating elements conforming to the basic relationship set forth in equation (3), can also be obtained in a construction in which the transverse segments of the heating elements are centered in segmental areas of equal size. A construction of this kind is illustrated in FIG. **5**, showing a heater plate **121** comprising lower and upper sections **121A** and **121B** with heating elements **125A** and **126A**. The incremental areas **A21** through **A28** of heater plate **121** are all equal in size and each contains a single resistive heat element.

From equations (1) through (3), it can be demonstrated that the construction shown in FIG. **5** produces the same operational effect as the construction of FIG. **4** if the power outputs of the individual heating element segments are determined in accordance with the series relationships

(6) $W_1$=4.18 $LST_1$,

$W_2$=4.18 $LST_2$,...

$W_n$=4.18 $LST_n$and

(7) $T_1=T_oM$,

$T_2=(T_o-T_1)M,...$

$T_n=(T_o-T_1-...T_{n11})M$

in which

$n$ = total number of segments (8 in FIG. 5)

$T_1...T_n$ = fluid temperature rise in each segment

$L$ = constant to compensate for low line voltage and thermal losses

$W_1...W_n$ 31 power input for each segment

and in which

$$M=1-e^{\frac{-2KPA}{nDS}} \quad (8)$$

This construction is practical and effective, but does require fabrication of individual legs for the heater element segments that are different from each other, and thus entails a larger number of individual parts than the variable-displacement construction of FIG. 4.

Applying the parameters set forth above to the construction illustrated in FIG. 5, the power requirements for the eight heating element segments in plate areas A21 through A28 (FIG. 4) are as follows:

$W_1$=watts

$W_2$=watts

$W_3$=watts

$W_4$=watts

$W_5$=watts

$W_6$=watts

$W_7$=watts

$W_8$=watts

It may be noted that the power requirements $W_1$—$W_4$ for the first four segments (areas A21—A24) total 450 watts and that the power requirements $W_5$—$W_8$ for the next four segments (areas A25—A28) total 150 watts. Thus, the Power requirements are the same for the construction of FIG. 5 as for that of FIG. 4, as long as the basic operational requirements remain unchanged. It can also be shown that the temperature rise and thermal conditions for the heater plates are essentially the same for both heater element constructions.

The fluid warmer to the invention is highly convenient and accessible in use. It requires but a moment to open door 14, to remove sac 16 from the fluid warmer, and to place a new sac in the fluid warmer and close the door. This is the total action required to change the fluid warmer from operation with one blood pumping system to another. If there is any leakage from sac 16, or contamination from any other source, all of the heating surfaces are fully accessible and available for cleaning. Thus, the fluid warmer presents no sanitation problem, an important consideration in emergency room and like applications.

The precision tapering of the electrical heating elements in the fluid warmer of the present invention enable the warmer device to maintain a substantially constant output temperature over a wide range of fluid flow rates. That is, the proportioning of the electrical heater elements in accordance with the heat absorption rate of the blood or other clinical fluid affords a precise thermal control that gives the blood warmer a substantially margin of safety in operation, without requiring an elaborate multithermostat circuit or other complex controls.

We claim:

1. A dry heat clinical fluid warmer for use in warming refrigerated blood and other fluids to a safe usable transfusion temperature, at any flow rate from zero to a given maximum rate, comprising:

a first thermally conductive heat plate;

a second thermally conductive heater plate;

mounting means mounting said first and second heater plates for pivotal movement, relative to each other, between a closed position in which said heater plates are disposed in closely spaced parallel relation to each other and an open position in which said heater plates are disposed at a relatively wide angle to each other;

a thin, flat, disposable fluid sac having inlet and outlet openings at opposite ends thereof;

support means for removably supporting said sac in predetermined position on one of said heater plates, when the heater plates are in open position, opposite sides of said sac contacting said first and second heater plates, respectively, when said heater plates are in closed position and said sac is filled with fluid;

first and second electrical heating elements, individually associated with said first and second heater plates, respectively, each of said heating elements being effectively tapered from the end thereof adjacent the sac inlet to the end adjacent the sac outlet so that the heat output of said heating elements gradually diminishes form the inlet end of said sac to the outlet end thereof in direct proportion to the diminishing rate of heat absorption by fluid moving from the sac inlet to the sac outlet, each heating element comprising at least two sections, arranged in sequence between the sac inlet and the sac outlet; and

precision thermal control means, thermally connected to at least one of said heater plates and electrically connected to said heating elements, for controlling operation of said heating elements in accordance with the temperature of said heater plate, said control means including separate thermostats for controlling the respective sections of each heating element.

2. A dry heat clinical fluid warmer according to claim 1 in which said mounting means mounts said heater plates in vertical alignment with one of said heater plates pivotally movable about a vertical axis, in which the sections of each heating element are mounted one above the other, and in which the sac inlet is located at the bottom of the heater plates and the sac outlet is located at the top of the heater plate.

3. A dry heat clinical fluid warmer according to claim 1 in which the taper of said heating elements is determined in accordance with the basic relationship

$$T=T_0\left[1-e^{\frac{-KAP}{DS}}\right]$$

where

$T$ = fluid temperature at a given time

$T_o$ = plate temperature above initial fluid temperature

$D$ = thermal conductivity of sac

$A$ = contact area of one plate

$D$ = thickness of sac

$S$ = maximum liquid flow rate

$P$ = ratio of effective contact area to actual plate area

all expressed in the c.g.s. system.

4. A dry heat clinical fluid warmer according to claim 3 in which each of said heating elements comprises a series of $n$ transverse segments each centered in a segmental area of its associated plate, from the sac inlet end of the plate to the sac outlet end, said segmental areas of said plates being determined in accordance with the series relationship:

$$A_1=\frac{DS}{2PK}\ln\left[\frac{T_0}{T_0-T'}\right]$$

$$A_1+A_2=\frac{DS}{2PK}\ln\left[\frac{T_0}{T_0-2T'}\right]$$

$$A_1+A_2\ldots+A_n=\frac{DS}{2PK}\ln\left[\frac{T_0}{T_0-nT'}\right]$$

where

$A_1$ = first segmental plate area, at inlet end

$A_2$ = second segmental plate area

$A_n$ = last segmental plate area, at outlet end

$T'$ = fluid temperature rise per segment all expressed in the c.g.s. system.

5. A dry heat clinical fluid warmer according to claim 4, in which said mounting means mounts said heater plates in vertical alignment, in which each electrical heating element comprises two sections, one above the other, with each heating

element section distributed in accordance with said series relationship, and in which said precision thermal control means includes a first main thermostat for control of both of the lower heat element sections and a second main thermostat for control of both of the upper heating element sections.

6. A dry heat clinical fluid warmer according to claim 3 in which each of said heating elements comprise a series of $n$ transverse segments centered in $n$segmental areas of equal size on its associated plate, from the sac inlet end of the plate to the sac outlet end, the power inputs to said heating element segments being determined in accordance with the series relationships

$W_1=LST_1,$

$W_2=LST_2,...$

$W_n=LST_n$

and

$T_1={}_oM,$

$T_2=(T_o-T_1)M,...$

$T_n=(T_o-T_1-...T_{n-1})M$

wherein



$$M=1-e^{\frac{-2KPA}{nDS}}$$

and where

$T_1...T_n$ = fluid temperature rise in each segment

$L$ = constant to compensate for low-line voltage and thermal losses

$W_1...W_n$ = power input for each segment

all expressed in the c.g.s. system.

7. A dry heat clinical fluid warmer according to claim 6, in which said mounting means mounts said heater plates in vertical alignment, in which each electrical heating element comprises tow sections, one above the other, with each heating element section distributed in accordance with said series relationships, and in which said precision thermal control means includes a first main thermostat for control of both of the lower heating element sections and a second main thermostat for control of both of the upper heating element sections.