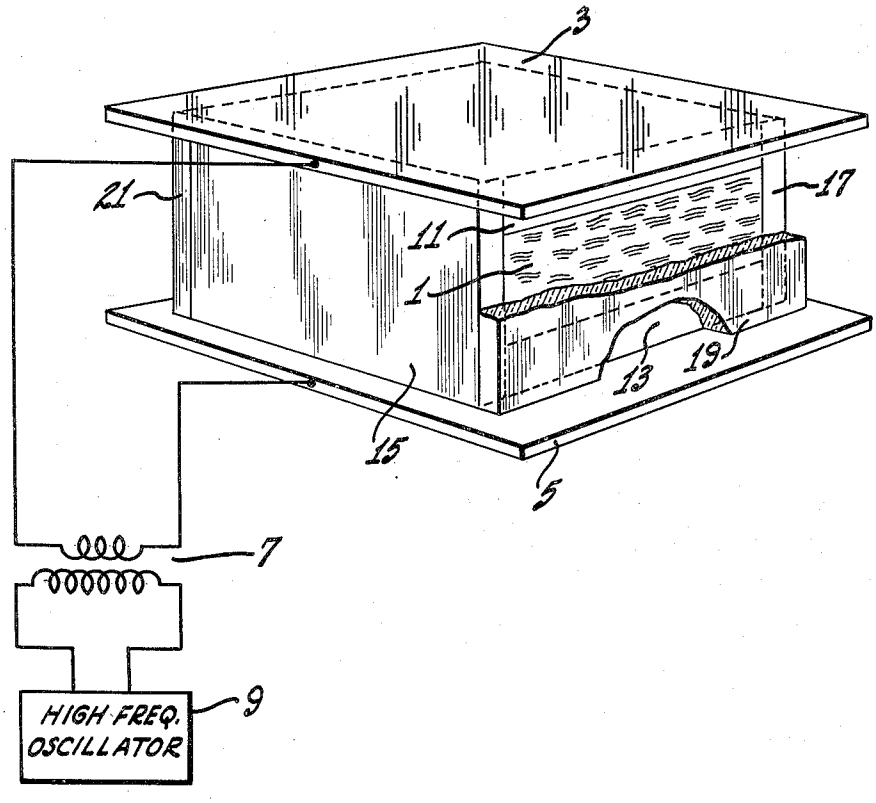
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ELECTRONIC HEATING METHOD AND APPARATUS

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ELECTRONIC HEATING METHOD AND APPARATUS

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This invention relates to a method of and apparatus for electronically heating dielectric materials, and more particularly to a method of and apparatus for heating such materials in a manner which will avoid substantial temperature differentials between various parts of the work as it is being heated.

It has been proposed heretofore to heat dielectric material by subjecting it to the influence of a high frequency electric field which produces dielectric losses therein and thus raises its temperature. The common practice is to place the dielectric material between a pair of metallic electrodes which are connected to a source of radio or other high frequency electric energy, the material or work being usually exposed to the ambient except where the electrodes contact it. With this condition, a very substantial quantity of the heat developed in the work is dissipated through the cold electrodes and the surrounding air, so that the work is not of uniform temperature throughout, being hottest in the central or inner region. If the work is raised at its inner region to a temperature requisite for a certain, desired effect, the outer regions thereof have not yet reached that temperature and therefore have not attained that effect; and if the outer regions are brought to the desired temperature, the inner region must be overheated and very frequently "overdone," so to speak. In either case, non-uniform heating of the entire mass of material results in an unsatisfactory product.

The primary object of my present invention is to provide an improved method of and apparatus for heating dielectric materials, which method and apparatus will not be subject to the aforementioned difficulty.

More particularly, it is an object of my present invention to provide an improved method of and apparatus for heating dielectric materials electronically which will heat the work uniformly throughout.

Another object of my present invention is to provide an improved method and apparatus as aforesaid which will eliminate appreciable temperature differentials in the work due to heat absorportion by the cold electrodes and surrounding air or other cold medium.

It is also an object of my present invention to provide an improved method and apparatus as aforesaid which will be economical to practice

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and use, and which will be highly efficient in use.

According to my present invention, the mass of dielectrical material which is to be heated electronically is surrounded by dielectric media which are heated by the same high frequency, electric field as the mass of work itself. The surrounding media should have such electrical characteristics and be of such thickness that, when heated, they will take up most of the temperature gradients due to cooling. The thickness of the surrounding media will depend, among other things, on the temperature of the ambient and the length of the heating cycle. In general, power factors and dielectric constants of materials suitable for the surrounding media which are disposed in the direction of the electric field which accomplishes the heating should be different from those of the materials suitable for the surrounding media which are disposed in a direction normal to the field.

The invention, together with additional objects and advantages thereof, will be better understood by reference to the accompanying drawing, in which the single figure is a perspective view, partly broken away, of one form of apparatus in accordance with my present invention.

Referring more particularly to the drawing, there is shown a mass of dielectric material 1 which is to be heated. For this purpose, the material 1 is placed between a pair of electrodes 3 and 5 which are connected, through a transformer 7, to a source of high frequency, electric energy 9, such as a vacuum tube oscillator operating at radio or some other suitable high frequency. In the illustrated embodiment, the work 1 is represented as a mass of cork which may be made of cork granules mixed with a suitable cement which is activated by the heat produced by the high frequency field which is set up between the electrodes 3 and 5.

The electrodes 3 and 5 and, of course, the surrounding air are at room temperature and much colder than the heated mass 1. If the work 1 is directly in contact with the cold electrodes 3 and 5 and its sides and ends are exposed to the air or other ambient, as is the customary, prior art practice, the heat developed in the outer regions of the mass 1 flows out rather rapidly through the electrodes and the surrounding air. Thus, while the inner region of the mass 1 remains hot enough to produce the desired effect

(setting of the adhesive and bonding of the cork particles in the case illustrated), the outer regions thereof are at a lower temperature and do not attain the desired effect. If more power is put into the work to compensate for heat losses in the outer regions and to bring these regions up to the requisite temperature, then the inner region becomes overheated and frequently scorched.

This difficulty is avoided, according to my present invention, by placing around the work or mass 1 suitable dielectric media which are also immersed in the high frequency, electric field and which are also heated by this field simultaneously with the work. The surrounding media shown in the drawing comprise a sheet, block or other suitable member 11 placed on top of the mass 1 and on which the electrode 3 rests; a similar member 13 under the mass 1 and engaged by the electrode 5; a pair of side members 15 and 17 which are in contact with the sides of the work 1; and a pair of end members 19 and 21 which are in contact with the ends or end faces of the work 1. All of the work surrounding members 11, 13, 15, 17, 19 and 21 are disposed between the electrodes 3 and 5 and, being of dielectric material, are all heated by the high frequency electric field set up therebetween in known manner at the same time that the work 1 is heated.

When the surrounding members 11, 13, 15, 17, 19 and 21 become hot, they act as heat insulators to prevent substantial flow of heat out of the outer regions of the work 1, thereby maintaining the entire mass of the work 1 at a practically uniform temperature requisite for the desired effect. It will be noted that the members 11 and 13 are disposed crosswise of the direction of the electric field which is set up between the electrodes 3 and 5, whereas the members 15, 17, 19 and 21 are disposed lengthwise of the field. For this reason, it is generally necessary that the members 11 and 13 be made of one material and the members 15, 17, 19 and 21 of another material. I have found that, in most cases, if all of the heat insulating members which surround the work are made of the same material, they will usually be heated to different temperatures and hence the heat flow out of the outer regions of the work will not be controlled uniformly. On the other hand, if the surrounding members are made of different, suitable materials depending upon whether they extend parallel to the direction of the electric field or at a right angle thereto, they will all absorb a quantity of high frequency power necessary to raise them all to substantially the required temperature.

For the sake of convenience, the positions of the surrounding members 11, 13, 15, 17, 19 and 21 may be defined with reference to the position of the work 1 and the direction of the electric field. Thus, the members 11 and 13 and the work 1 may be considered in series in the direction of the field, and the members 15, 17, 19, 21 and the work 1 may be considered in parallel relation with respect to the field, although being also in series in a direction normal to that of the field. This designation is an arbitrary one and is resorted to as a convenient way of defining the "heat factors" which should prevail in the work and in the various surrounding members if uniform heating is to be obtained in accordance with my invention.

Considering, first, the work 1 and the "series" members 11 and 13, the "series" heat factor, or one of the factors which determines the quantity of heat to be developed in any elemental, unit volume of either the work 1 or the members 11 and 13, is defined by the equation

$$\text{H. F. (series)} = \frac{\text{P. F.}}{KSd} \qquad (1)$$

where

H. F.=the heat factor,

P. F.=power factor (expressed as a decimal) of the work 1 and the members 11 and 13,

K=dielectric constant of either the work 1, the member 11 or the member 13, depending upon which is being considered,

S=specific heat of either the work 1, the member 11 or the member 13, depending upon which is being considered, and

d=density (expressed as lbs./cu. in.) of either the work 1, the member 11 or the member 13, depending upon which is being considered.

On the other hand, considering the work 1 and the members 15, 17, 19 and 21, the "parallel" heat factor, that is, one of the factors which determines the quantity of heat to be developed in any elemental, unit volume of the work or the members 15, 17, 19 and 21, is defined by the equation

$$\text{H. F. (parallel)} = \frac{K(\text{P. F.})}{Sd} \qquad (2)$$

where each of the terms has the same meaning as above.

For an explanation of the derivation of the parallel heat factor formula, assume that two or more materials are arranged in parallel dielectric paths between a pair of R.-F. heating electrodes or applicator plates, as for example members 15, 17, 19, 21 and the work 1. Material 1 has a power factor $(\text{P. F.})_1$, dielectric constant K_1, density d_1, and specific heat S_1. Similarly material 2 has a power factor $(\text{P. F.})_2$, dielectric constant K_2, density d_2, and specific heat S_2. Material 3 has similar appropriate subscript designations, etc. When a common voltage E is applied to the assembly, the equivalent electrical circuit includes a total capacitance C, where C_1 represents material 1, C_2 represents material 2, etc. Under these conditions the current in material 1 is I_1, in material 2 it is I_2 and in material 3 it is I_3. Furthermore assume that all materials have the same physical dimensions; that is, the same area, thickness and volume. The generator E will supply a total power P to the different materials. The power in material 1 will be P_1, that in material 2 P_2 and in 3 P_3. Then we have

$$P = P_1 + P_2 + P_3 \qquad (3)$$

But the power in any material is equal to the voltage across it, times the current in it, times the power factor of the material. Then since the voltage is common we have

$$P = EI_1(\text{P. F.})_1 + EI_2(\text{P. F.})_2 + EI_3(\text{P. F.})_3 \qquad (4)$$

Furthermore, the current in a capacitor C is

$$I = E\omega C$$

Therefore

$$P = E^2\omega C_1(\text{P. F.})_1 + E^2\omega C_2(\text{P. F.})_2 + E^2\omega C_3(\text{P. F.})_3 \qquad (5)$$

The capacity of a capacitor C, filled with a dielectric K is (neglecting strays)

$$C = KC_x$$

Where C_x is the capacity with the dielectric removed (air condenser). Then

$$C_1 = K_1C_x \qquad (6)$$

$$C_2 = K_2C_x \qquad (7)$$

$$C_3 = K_3C_x \qquad (8)$$

Substituting (6), (7) and (8) in (5) and collecting terms we have

$$P=E^2\omega C_x[K_1(\text{P. F.})_1+K_2(\text{P. F.})_2+K_3(\text{P. F.})_3] \quad (9)$$

The product K(P. F.) is recognized as the loss factor and we may write

$$P=E^2\omega C_x[(\text{L. F.})_1+(\text{L. F.})_2+(\text{L. F.})_3] \quad (10)$$

The loss factor adequately describes the relative power absorbed by a material. When multiplied by the common term ($E^2\omega C_x$) we obtain the actual power in watts dissipated in that material.

When we wish to compare temperatures, however, several other factors must be considered. First let us derive the total power in material 1 from purely physical constants. A block of material having weight M, specific heat S, will be raised in temperature ΔT degrees in a time, t, by a power input P; that is

$$P_1=\frac{M_1S_1(\Delta T)_1}{tG} \quad (11)$$

where G is a numerical constant. P_2 and P_3 can be written similarly.

But from (7) we found that the power in P_1 was

$$P_1=E^2\omega C_xK_1(\text{P. F.})_1 \quad (12)$$

Equating (9) and (10) we have

$$\frac{M_1S_1(\Delta T_1)}{tG}=E^2\omega C_xK_1(\text{P. F.})_1 \quad (13)$$

from which we obtain

$$(\Delta T)_1=\frac{E^2\omega C_xtGK_1(\text{P. F.})_1}{M_1S_1} \quad (14)$$

But

$$M_1=Vd_1 \quad (15)$$

Where V is the volume of the material, assumed constant for all materials, and d is the density

$$(\Delta T)_1=\frac{E^2\omega C_xtG}{V}\left[\frac{K_1(\text{P. F.})_1}{d_1S_1}\right] \quad (16)$$

The bracketed term is the heat factor, $(\text{H. F.})_1$, of material 1.

For material 2 it is

$$(\text{H. F.})_2=\frac{K_2(\text{P. F.})_2}{d_2S_2}$$

or

$$\text{H. F. (parallel)}=\frac{K(\text{P. F.})}{Sd} \quad (17)$$

which is the same as Equation 2

Therefore, the heat factor adequately indicates the relative temperature rise in each material. When multiplied by the common term

$$\left[\frac{E^2\omega C_xtG}{V}\right]$$

we obtain the temperature rise in that material.

Instead of the parallel arrangement above considered, assume the materials are stacked serially between the electrodes, as for example the materials 11, 1 and 13 in the drawing. The equivalent electrical circuit will include the capacity C between the electrodes comprising the three bodies of material in series. The same assumptions with respect to dimensions and constants are made. The total power is

$$P=P_1+P_2+P_3 \quad (18)$$

Since the current is common to all materials in this case and the voltages across each block are different, we write

$$P=E_1I(\text{P. F.})_1+E_2I(\text{P. F.})_2+E_3I(\text{P. F.})_3 \quad (19)$$

But

$$E_1=\frac{I}{\omega C_1} \quad (20)$$

$$E_2=\frac{I}{\omega C_2} \quad (21)$$

$$E_3=\frac{I}{\omega C_3} \quad (22)$$

Then

$$P=\frac{I^2}{\omega C_1}(\text{P. F.})_1+\frac{I^2}{\omega C_2}(\text{P. F.})_2+\frac{I^2}{\omega C_3}(\text{P. F.})_3 \quad (23)$$

Also

$$DC_1=K_1C_x \quad (24)$$

$$C_2=K_2C_x \quad (25)$$

$$C_3=K_3C_x \quad (26)$$

Substituting

$$P=\frac{I^2}{\omega C_x}\left[\frac{(\text{P. F.})_1}{K_1}+\frac{(\text{P. F.})_2}{K_2}+\frac{(\text{P. F.})_3}{K_3}\right] \quad (27)$$

This equation is identical in form with Equation 9. Hence we deduce that the loss factors for the series arrangement of the dielectrics have the general form

$$\text{L. F.}=\frac{\text{P. F.}}{K} \quad (28)$$

It is possible to define a corresponding heat factor in the same manner as for Figure 1. For material 1 the power is given by Equation 11, and from Equation 27 we see that we may also write

$$P_1=\frac{I^2(\text{P. F.})_1}{\omega C_xK_1} \quad (29)$$

Combining Equations 11 and 29

$$\frac{M_1S_1(\Delta T_1)}{tG}=\frac{I^2(\text{P. F.})_1}{\omega C_xK_1} \quad (30)$$

Solving for $(\Delta T)_1$

$$\Delta T_1=\frac{I^2(\text{P. F.})_1tG}{M_1S_1\omega C_xK_1} \quad (31)$$

But

$$M_1=Vd_1 \quad (32)$$

Substituting

$$\Delta T_1=\frac{I^2tG}{V\omega C_x}\left[\frac{(\text{P. F.})_1}{d_1S_1K_1}\right] \quad (33)$$

Equation 33 is similar to Equation 16 and the heating factor for the series arrangement has the general form

$$\text{H. F. (series)}=\frac{\text{P. F.}}{KSd} \quad (34)$$

which is the same as Equation 1.

From the foregoing considerations it will be seen that the heat factors provide a definite index of the temperatures obtainable for the series and parallel dielectric heating paths provided between the electrodes. In the consideration of the first case for parallel heating paths, the voltage, time, and the capacity between the electrodes remains constant for all of the various parallel paths and the material therebetween. Likewise, in considering the second case for series heating paths, the current through the material, the time, the volume of the material, and the capacity between the electrodes are all constant with respect to the current path considered.

Therefore, the temperature rise in a definite time period may be expressed by the Equation 16 for the parallel paths and by the Equation 33 for the series arrangement which includes the work body or mass of dielectric material. The materials may be so chosen that the proper constants therefor in the equations give a desired temperature rise, that is the temperature of the external envelope may be substantially the same as the internal temperature of the dielectric mass.

From the foregoing, it will be apparent that if the surrounding members are all made of the same material and different from that of the work 1, they will not all reach the same temperature for a given field strength. Furthermore, although it is possible for either the "series" members 11 and 13, or the "parallel" members 15, 17, 19 and 21 to reach the same temperature as the work 1 by a suitable choice of constants, it is generally not possible for all of the surrounding members to reach this temperature simultaneously unless they are made of different materials. The only condition under which all of the work-surrounding members will reach the same temperature as the work is if they have identical constants with the work (for example, when they are made of the same material). Otherwise, they should be made of different materials as shown above.

Although I have shown and described one form of apparatus embodying my present invention and one method of carrying the same out in practice, it will undoubtedly be apparent to those skilled in the art that many variations thereof are possible. I therefore do not wish to be limited to the precise apparatus and method disclosed, but only by the prior art and by the spirit of the appended claims.

I claim as my invention:

1. In electrical heating apparatus for heating a dielectric mass with the aid of a high frequency electric field, the combination of a pair of spaced R.-F. heating electrodes between which said mass is adapted to be disposed and between which said field may be set up, and dielectric means also interposed between said electrodes within the confines of said field adapted to surround said dielectric mass, said dielectric means being constituted by a plurality of members certain ones of which are disposed in the direction of said field, are made of a material other than said mass and have a parallel heat factor such as to permit attainment of substantially the same temperature as said mass when in said electric field, and certain others of which are disposed in a direction normal to said first named direction, are made of a material other than said mass and have a series heat factor such as to permit attainment of substantially the same temperature as said mass when in said electric field, said parallel heat factor being determined from the equation

$$\text{H. F. (parallel)} = \frac{K\ (\text{P. F.})}{Sd}$$

and said series heat factor being determined from the equation

$$\text{H. F. (series)} = \frac{\text{P. F.}}{KSd}$$

where

P. F.=power factor of said members,
K= dielectric constant of said members,
S=specific heat of said members, and
d=density of said members, said members

when heated as a result of dielectric losses produced therein by said field, serving to substantially prevent the flow out of the outer regions of said mass of the heat developed therein by said field, and said members having such characteristics, including power factor, dielectric constant, specific heat and density, as to maintain said mass at a substantially uniform temperature throughout when said members and mass are heated by said field.

2. In electrical heating apparatus for heating a dielectric mass with the aid of a high frequency electric field, the combination of a pair of spaced R.-F. heating electrodes between which said mass is adapted to be disposed and between which said field may be set up, and dielectric means also interposed between said electrodes within the confines of said field adapted to surround said mass, certain of said dielectric means providing an R.-F. current path between said electrodes through said dielectric mass for heating said dielectric means and said mass and being made of a material other than said mass having a series heat factor such as to permit attainment of substantially the same temperature as said mass when in said electric field, said series heat factor being determined from the equation

$$\text{H. F. (series)} = \frac{\text{P. F.}}{KSd}$$

and certain others of said dielectric means providing a plurality of other R.-F. current paths in parallel with said first named path between said electrodes and external to said mass for heating said last named dielectric means simultaneously with said mass and dielectric means in the first named path and being made of a material other than said mass, having a parallel heat factor such as to permit attainment of substantially the same temperature as said mass when in said electric field, said parallel heat factor being determined from the equation

$$\text{H. F. (parallel)} = \frac{K\ (\text{P. F.})}{Sd}$$

where

P. F.=power factor of said dielectric means,
K=dielectric constant of said dielectric means,
S=specific heat of said dielectric means,
d=density of said dielectric means,

said dielectric means providing boundary temperatures for said dielectric mass substantially equal to the internal temperature thereof, whereby internal overheating of said dielectric mass with respect to the boundaries thereof is prevented.

3. In electrical heating apparatus for heating a dielectric mass with the aid of a high frequency electric field, the combination of a pair of spaced R.-F. heating electrodes between which said mass is adapted to be disposed and between which said field may be set up, and dielectric means also interposed between said electrodes within the confines of said field adapted to surround said mass, certain of said dielectric means providing walls between each of said electrodes and said dielectric mass and an R.-F. current path between said electrodes through said dielectric mass and being made of a material other than said mass having a series heat factor such as to permit attainment of substantially the same tem-

perature as said dielectric mass when in said electric field and determined from the equation

$$\text{H. F. (series)} = \frac{\text{P. F.}}{KSd}$$

and others of said dielectric means providing side and end walls about said dielectric mass providing a plurality of additional R.-F. current paths in parallel with said first named path between said electrodes and external to said dielectric mass and being made of a material other than said mass, having a parallel heat factor such as to permit attainment of substantially the same temperature as said dielectric mass when in said electric field and determined from the equation

$$\text{H. F. (parallel)} = \frac{K\ (\text{P. F.})}{Sd}$$

where

P. F.=power factor of said dielectric means,
K=dielectric constant of said dielectric means,
S=specific heat of said dielectric means,
d=density of said dielectric means,

whereby said first named walls and said side and end walls are heated by R.-F. currents in parallel current paths simultaneously with said mass and substantially uniform heating is provided for said dielectric mass.

4. In the art of heating dielectric material with the aid of a high frequency electric field, the method which comprises completely surrounding a body of said material with dielectric media along all the faces thereof, and applying said field in a certain direction simultaneously to said body and said media to obtain a uniform temperature throughout said body, so much of said media as is disposed in series with said body in said direction being characterized by having a

series heat factor which is expressed by the equation

$$\text{H. F. (series)} = \frac{\text{P. F.}}{KSd}$$

and so much of said material as is disposed in parallel with said body in said direction being characterized by having a parallel heat factor which is expressed by the equation

$$\text{H. F. (parallel)} = \frac{K\ (\text{P. F.})}{Sd}$$

where

H. F.=heat factor,
P. F.=power factor of said media,
K=dielectric constant of said media, and
d=density of said media,

both series and parallel heat factors being such that both said body and said media attain substantially the same temperature when in said electric field.

GEORGE W. KLINGAMAN.

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