

June 5, 1956

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2,748,868

WELL HEATER

Filed July 19, 1954

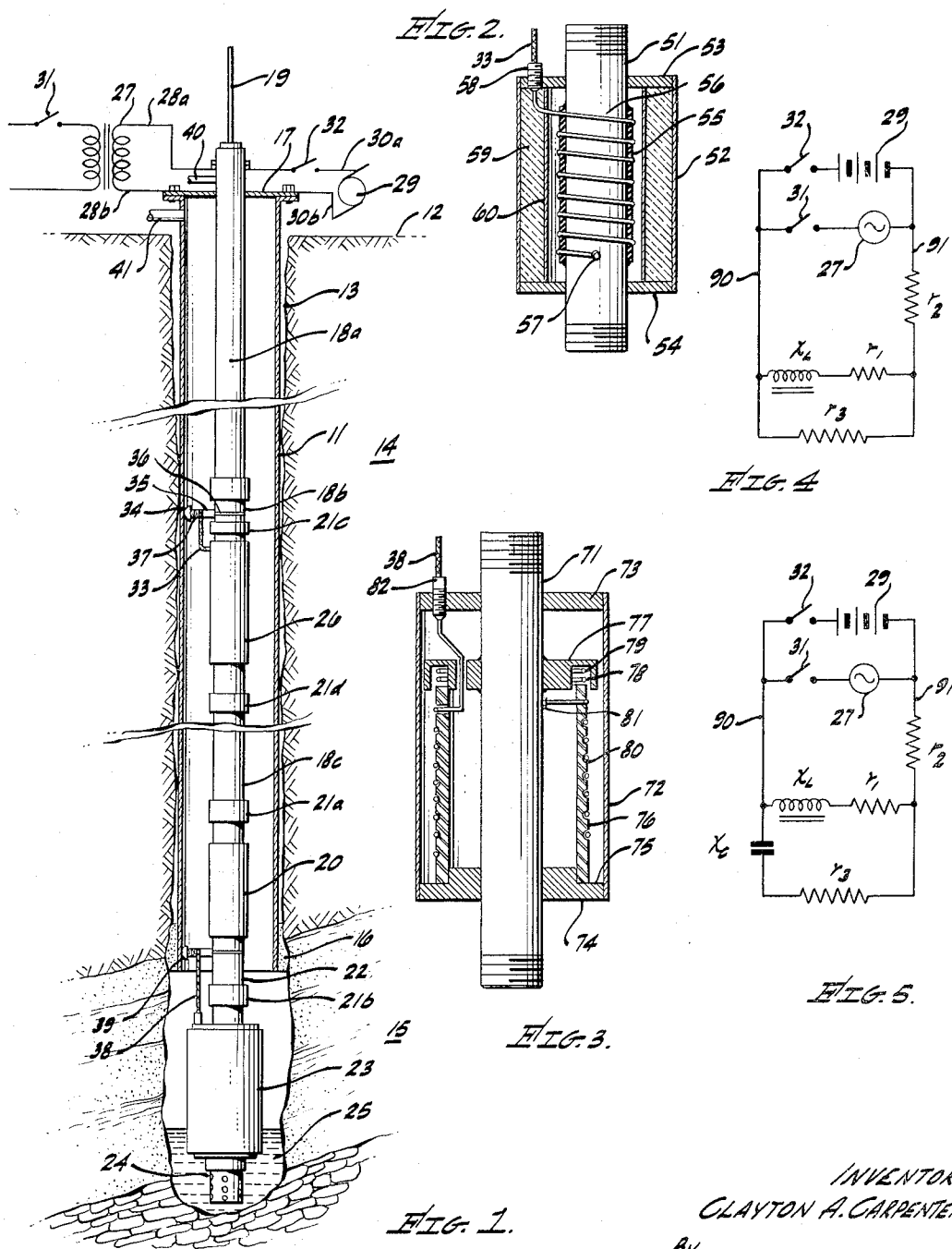


FIG. 1.

FIG. 3.

FIG. 4

FIG. 5.

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2,748,868

WELL HEATER

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Application July 19, 1954, Serial No. 444,297

14 Claims. (Cl. 166—60)

This invention relates to a device for heating oil wells and the like, and in particular relates to a well heating apparatus adapted to heat either the oil within the tubing string, the oil-producing formation itself, or both.

It has long been realized that in many oil wells the application of heat to the oil-producing formation itself or to the oil within the well tubing string would secure a material increase in the amount of oil produced from the well, and a wide variety of electric heaters have been proposed for such purpose. For the most part, however, such heaters have proven unsuccessful, primarily by reason of the difficulties involved in adequately insulating the heating element and the cables for supplying electric current to the same. In a number of instances it has been proposed to eliminate at least some of these difficulties by employing various members of the well structure, e. g., the tubing string and the casing, the sucker rod string and the tubing, etc., as conductors for the electric current, but such systems have not permitted the selective operation of more than one heater.

It is an object of the present invention to provide an electric well heating device which can be selectively operated to apply heat either to the oil-bearing formation or to the oil in the tubing string, or both.

A further object is to provide a means for eliminating the use of separate cables for supplying current to a well heater of such type.

A more general object is to provide an improved electric well heater.

Other and related objects will be apparent from the following detailed description of the invention, and various advantages not specifically pointed out herein will occur to those skilled in the art upon employment of the invention in practice.

I have now found that the above objects and attendant advantages may be realized in an apparatus which comprises a first heater adapted to transfer heat to the oil within the tubing string and a second heater adapted to transfer heat to the oil-bearing formation and/or to the pool of oil at the bottom of the well. Electric current is supplied to both of said heaters via the tubing string and well casing. One of the heaters is inductively wound so that it will pass direct current but constitute a relatively high resistance to the passage of alternating current, and will hence generate heat upon being supplied with direct current. The other heater is non-inductively wound and presents relatively high resistance to the passage of direct current, and will hence generate heat upon being supplied with alternating current. The resistance and inductance values of the two heaters are so selected that the two heating elements can be operated selectively by changing the type of current supplied. If desired, both heaters may be operated simultaneously by supplying alternating current having a direct current component.

In the accompanying drawing which forms a part of this application, and in the several figures in which like numerals designate like parts:

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Figure 1 illustrates a typical well bore having the heating device of the present invention disposed therein.

Figure 2 illustrates one form which the heater which is adapted to transfer heat to the oil in the tubing string may take.

Figure 3 illustrates one form which the heater which is adapted to transfer heat to the oil-bearing formation and/or a pool of oil at the bottom of the well may take.

Figure 4 diagrammatically illustrates the equivalent electrical circuit of the heating device.

Figure 5 diagrammatically illustrates the equivalent electrical circuit of a modified heating device within the scope of the invention.

Referring now to Figure 1 of said drawing, well casing 11 extends downwardly from the earth's surface 12 through well bore 13 traversing various sub-surface strata 14 into oil-bearing formation 15, and is cemented to the walls of the bore at its lower end by the conventional cement plug 16. Casing 11 is capped at the surface with tubing head 17 which supports tubing string 18a, 18b, and 18c within the casing. Sucker rod string 19 extends downwardly within the tubing string to reciprocating well pump 20 inserted in the tubing string by means of coupling 21a. Lower connecting nipple 22 of pump 20 is connected to bottom hole heater 23 by means of coupling 21b, and perforate skitter bill 24 extends downwardly from bottom hole heater 23 into oil pool 25 at the bottom of the bore. Within the upper part of the bore, tubing heater 26 is inserted into the tubing string by means of couplings 21c and 21d. Alternating current from a suitable source 27 may be applied across the tubing string and casing through conductors 28a and 28b, and direct current from a suitable source 29 may be applied across the tubing string and casing through conductors 30a and 30b. Switches 31 and 32 allow selection of the type of current to be so applied. Tubing heater 26 is constructed so that one terminal of the heating element therein is electrically connected to the tubing string. The other terminal is connected to a short length of insulated cable 33 which passes through the exterior wall of the heater and terminates in contact 34 supported by, but electrically insulated from, the tubing string. Contact 34 may suitably take the form of a metallic button or brush mounted on an insulator 35 which is affixed to the tubing string by clamp 36. A spring 37 causes contact 34 to press against casing 11 and establish good electrical contact therewith. The electric current passes from the source thereof down through tubing 18a and 18b to the heating element, through the heating element and cable 33 to contact 34, and thence up through casing 11 and back to the source of power. Bottom hole heater 23 is similarly connected, the circuit comprising the tubing string, the heating element within the heater, cable 33, contact 39 and casing 11.

Operation of the assembly illustrated in Figure 1 is as previously stated. By closing switch 31 alternating current is applied across the tubing string and casing 11 and will be conducted to heaters 26 and 23 via contacts 34 and 39 and cables 33 and 38, respectively. One of said heaters, however, is so constructed that it presents a high impedance to alternating current. Accordingly, a major part of the current will pass through the other (non-inductive) heater and will generate heat which is transferred either to the oil in the tubing string or to the oil-bearing formation 15 and/or oil pool 24 depending upon which of the heaters 26 and 23 presents the high impedance to alternating current. Alternatively, by closing switch 32, direct current is applied across the tubing and casing, and, by reason of having properly fixed the resistance and impedance values of the respective heaters as is hereinafter more fully explained, will preferentially pass through that heater which presents a high impedance to alternat-

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ing current and will generate heat therein to be transferred to that part of the well which is adjacent thereto. By closing both switches 31 and 32 the current applied is direct with an alternating component, whereby both heaters will operate simultaneously and heat will be transferred both to the oil in the tubing string and to oil-bearing formation 15 and/or oil pool 25. During heating with either or both heaters, pump 20 is operated by reciprocation of sucker rod string 19, thereby raising oil from pool 25 up through the tubing string to production pipe 40 at the earth's surface. Annulus pipe 41 is provided in well casing 11 for the discharge of gas from, or the introduction of gas into, the well annulus.

Referring now to Figure 2, which illustrates one form which tubing heater 26 may take, said heater comprises a central oil-conducting conduit 51 suitably threaded at each end for connection to the well tubing. A cylindrical outer shell 52 is maintained coaxially disposed around conduit 51 by upper and lower closures 53 and 54, respectively. The latter are welded or otherwise attached to conduit 51 and outer shell 52 so as to provide a fluid-tight seal therebetween. Within the fluid-tight enclosure formed by closures 53 and 54 and outer shell 52, conduit 51 is provided with a ferro-enamel or other heat-conducting electrically-insulating coating 55 applied along a major portion of its length. Electric resistance heating coil 56 is wound around conduit 51 over insulation 55, and may be wound inductively as shown or non-inductively as by doubling back on itself to form a double helix. When wound as shown, coil 56 and conduit 51 together form an iron-core inductance which presents a relatively high impedance to the flow of alternating current and a relatively low resistance to the flow of direct current; in such case, bottom hole heater 23 should be non-inductive. One end of coil 56 is electrically connected to conduit 51 at terminal 57; the other end is connected to cable 33 at fitting 58 which passes through closure 53 to form a fluid-tight seal. In order that the heat generated by the passage of electric current through coil 56 may be directed inwardly towards the oil flowing through conduit 51 which forms a part of the tubing string, rather than outwardly through outer shell 52 and into the well annulus where it would be wasted, the space between coil 56 and outer shell 52 is at least in part filled with thermal insulation 59 held in place by inner shell 60 which also serves as a reflector to direct the heat back towards conduit 51.

Referring now to Figure 3, which illustrates a suitable form which bottom hole heater 23 may take, said heater comprises central oil-conducting conduit 71 threaded at each end to engage the well tubing, coaxially disposed outer cylindrical shell 72, and upper and lower closures 73 and 74, respectively, forming a fluid-tight seal between said shell and said conduit. Lower closure 74 is provided with a peripheral groove 75 which receives the lower end of cylindrical coil form 76 and maintains said coil form coaxially disposed around and spaced away from conduit 71. Retaining plate 77 is affixed to conduit 71 adjacent upper closure 73, and is provided with a peripheral groove 78 receiving the upper end of a coil form 76. A coil spring 79 carried in groove 78 assures positive engagement of the upper end of coil form 76 with groove 78 during expansion of the assembly upon heating. Coil form 76 is constructed of an electrical-insulating material to prevent short-circuiting of the turns of electric resistance heating coil 80 which is carried in the grooves thereof. Said material also has thermal insulating properties to impede the transfer of heat from coil 80 towards conduit 71 to promote said transfer of heat outwardly through shell 72 and thence to the adjacent oil-bearing formation and/or oil pool. If desired, the space between coil form 76 and conduit 71 may be filled with additional thermal insulation. As previously stated, if the heating coil in tubing heater 26 is wound inductively the heating coil 80 in the bottom hole heater is wound non-inductively in the known manner, and vice versa. Usually it is preferred

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that the tubing heater be inductive and the bottom hole heater be non-inductive. One end of coil 80 is electrically connected to conduit 51 at terminal 81, and the other end is carried up through plate 77 to fitting 82 leading through upper closure 73 where it is connected to cable 38.

In connection with the foregoing, concerning the construction of heaters 23 and 26, it will be realized that said heaters may take a wide variety of forms provided the following requirements are met:

1. The tubing heater must be adapted to transfer heat to an oil-conducting conduit which forms part of the tubing string and to the oil flowing therethrough, as opposed to transferring heat outwardly towards the walls of the well bore.

2. The bottom hole heater must be adapted to transfer heat outwardly towards the adjacent and surrounding oil-bearing formation and/or oil pool, as opposed to transferring heat inwardly towards the oil-conducting conduit which forms a part of the tubing string and to the oil flowing therethrough.

3. One of said heaters must be electrically inductive so as to present an impedance to the flow of alternating current, and the other must be non-inductive so as to allow alternating current to flow relatively freely therethrough.

Referring now to Figure 4, said figure diagrammatically illustrates the electric circuit of the device described above. Direct and alternating current sources 29 and 27, respectively, with their accompanying switches 32 and 31, respectively, are connected in parallel across the well casing and the well tubing represented by conductors 90 and 91. The combined resistance of these conductors is represented by resistance value r_2 . Within the well bore the two heaters are likewise connected in parallel across the conductors, i. e., across the well casing and the well tubing. The inductance and resistance of the inductively wound heater coil is represented by inductance and resistance values X_L and r_1 , respectively. The resistance of the non-inductively wound heater is represented by resistance value r_3 . In order for the device to operate as intended, these values must bear the following relationship to one another:

$$\begin{aligned} r_1 &\ll (r_2 + r_3) \\ X_L &\gg (r_2 + r_3) \end{aligned}$$

Since the heat generated by passage of current through r_2 is substantially lost, r_2 should be as low as possible, i. e., of the order of 5 ohms or less. Ideally, r_2 should be 0, whereby the above relationships reduce to:

$$\begin{aligned} r_1 &\ll r_3 \\ X_L &\gg r_3 \end{aligned}$$

The value of r_3 will depend upon how much heat it is desired to generate and transfer from the non-inductive heater and upon the potential at which the alternating current is supplied. In a typical installation, however, 60 cycle alternating current is employed at 440 volts and about 6 kilowatts of energy are dissipated at the bottom hole heater. Assuming the bottom hole heater to be the one which is non-inductive, as will almost always be the case, the value of r_3 under such typical operating conditions will be of the order of 30–35 ohms. In such case the resistance of the inductive heater, i. e., the value of r_1 , will be of the order of 5–10 ohms, and direct current will be supplied thereto at a potential of about 175–250 volts. Also, in such case, the impedance of the inductively wound tubing heater will be of the order of 500–750 ohms.

Considering the following typical circuit and voltage values:

70	A. C. voltage (60 cycles)-----volts--	440
	D. C. voltage-----do-----	220
	X_L at 60 cycles-----ohms--	500
	r_1 -----do-----	10
	r_2 -----do-----	2
75	r_3 -----do-----	30

Ohm's law calculations give the following power distributions:

	A. C.	D. C.
Power dissipated in transmission line (r_2), kw	0.435	1.08
Power dissipated in bottom hole (non-inductive) heater (r_3), kw	5.620	1.01
Power dissipated in tubing (inductive) heater ($X_L + r_1$), kw	0.331	3.02
Total power dissipated, kw	6.386	5.111

It will be seen that under the above conditions and on alternating current operation, of the total power dissipated at both heaters, about 92.8 per cent is dissipated at the non-inductive bottom hole heater, and on direct current operation about 74.8 per cent is dissipated at the inductive tubing heater. By increasing the difference between r_1 and r_3 a greater proportion of the total power will be dissipated at the inductive heater on direct current operation. Ordinarily, the heaters are so constructed that the direct current resistance of the non-inductive heater (r_3) is from about 2 to about 10 times that of the inductive heater (r_1), and the total alternating current impedance of the inductive heater ($X_L + r_1$) is from 10 to about 20 times that of the non-inductive heater (r_3). As previously stated, the resistance of the transmission line (r_2), which comprises the tubing string and the well casing or a cable should be as low as possible, preferably less than about 5 ohms.

Should it be desired to achieve substantially completely independent operation of the two heaters a capacitor may be placed in series with the non-inductive heater, whereby the circuit through the latter is entirely open insofar as the flow of direct current is concerned. As a result, all of the direct current will flow through the inductive heater. The equivalent electrical circuit of such arrangement is illustrated in Figure 5, wherein X_c represents the impedance which the capacitance presents to the flow of alternating current. The value of X_c should of course be much smaller than the value of X_L , and is suitably less than about 20 ohms. The capacitance will accordingly be at least about 130 mfd. when 60 cycle current is employed, or at least about 20 mfd. when 400 cycle current is employed. Ordinarily the frequency of the alternating current employed will be between 25 and 1000 cycles. The design and construction of capacitors of such capacity capable of being inserted into a well bore is known in the art.

Other modes of applying the principle of my invention may be employed instead of those explained, change being made as regards the structural elements and means employed provided the apparatus defined by any of the following claims, or the equivalent of such defined apparatus, be constructed.

I, therefore, particularly point out and distinctly claim as my invention:

1. A well heater for use in combination with a well tubing which is adapted to conduct oil from oil-bearing formations penetrated by the well bore to the earth's surface, comprising, in combination, a first electrical resistance heating element adapted to transfer heat to the oil passing through said tubing, a second electrical resistance heating element adapted to transfer heat to oil-bearing formations penetrated by the well bore and electrically connected in parallel with said first heating element, electrically conductive means for supplying electric current to said heating elements from sources of alternating and direct current located at the earth's surface, and switching means for electrically connecting either or both of said sources to said conductive means; one of said electrical resistance heating elements being electrically inductive so as to present substantial impedance to the flow of alternating current therethrough and the other of said heating elements being substantially non-inductive, the direct current resistance of the inductive heating element being substantially less than the sum of the direct cur-

rent resistance of the substantially non-inductive heating element and the direct current resistance of said conductive means, and the inductive reactance of the inductive heating element at the frequency of the said alternating current source being substantially greater than the sum of the direct current resistance of the substantially non-inductive heating element and the direct current resistance of said conductive means.

2. A device as defined in claim 1 wherein the said first electrical resistance heating element is electrically inductive and the said second electrical resistance heating element is substantially non-inductive.

3. A device as defined in claim 1 wherein the said electrically conductive means comprises the well tubing.

4. A device as defined in claim 1 wherein the direct current resistance of the substantially non-inductive heating element is from about 2 to about 10 times that of the inductive heating element and the total impedance of the inductive heating element at the frequency of the alternating current source is from 10 to 20 times that of the substantially non-inductive heating element.

5. A device as defined in claim 1 wherein an electrical capacitor is provided in series with the substantially non-inductive heating element to provide an impedance to the flow of direct current through said element, the capacitive reactance of said capacitor at the frequency of the alternating current source being substantially less than the inductive reactance of the inductive heating element.

6. A well heater comprising an imperforate central tube adapted to be coupled to the well tubing, a first cylindrical shell of larger diameter than said central tube affixed thereto and defining a first fluid-tight annular space extending along a portion of the length thereof, a first electrical resistance heating element disposed in said annular space in such manner as to transfer heat inwardly through the walls of said central tube, a second cylindrical shell of larger diameter than said central tube affixed thereto adjacent the lower end thereof defining a second fluid-tight annular space, a second electrical resistance heating element disposed in said annular space in such manner as to transfer heat outwardly through the walls of said shell to oil-bearing formations and/or an oil pool adjacent thereto, electrically conductive means for supplying electric current to said heating elements in parallel from sources of alternating and direct current located at the earth's surface, and switching means for electrically connecting either or both of said sources to said conductive means; one of said electrical heating elements being electrically inductive so as to present an impedance to the flow of alternating current therethrough and the other of said heating elements being substantially non-inductive, the direct current resistance of the inductive heating element being substantially less than the sum of the direct current resistance of the substantially non-inductive heating element and the direct current resistance of the said conductive means, and the inductive reactance of the inductive heating element at the frequency of the said alternating current source being substantially greater than the sum of the direct current resistance of the substantially non-inductive heating element and the direct current resistance of the said conductive means.

7. A device as defined in claim 6 wherein the said first electrical resistance heating element is electrically inductive and the said second electrical resistance heating element is substantially non-inductive.

8. A device as defined in claim 6 wherein the said electrically conductive means comprises the well tubing.

9. A device as defined in claim 6 wherein one terminal of each of said heating elements is electrically connected to the said well tubing and the other terminal of each of said heating elements is electrically connected to means exterior of each of said shells and adapted to frictionally engage and maintain electrical contact with the well casing.

10. A device as defined in claim 6 wherein the direct

current resistance of the substantially non-inductive heating element is from about 2 to about 10 times that of the inductive heating element and the total impedance of the inductive heating element at the frequency of the alternating current source is from 10 to 20 times that of the substantially non-inductive heating element.

11. A device as defined in claim 6 wherein an electrical capacitor is provided in series with the substantially non-inductive heating element to provide an impedance to the flow of direct current through said element, the capacitive reactance of said capacitor at the frequency of the alternating current source being substantially less than the inductive reactance of the inductive heating element.

12. A device as defined in claim 6 wherein a well pump is provided in the said central tube between the said first and second shells.

13. A device for heating oil wells comprising an impermeate central tube adapted to be coupled to the well tubing, a first cylindrical shell having a diameter larger than that of said central tube but smaller than that of the well casing and affixed to said central tube by a first set of spaced annular closures forming a fluid-tight seal between said central tube and said first shell, a first electrical resistance heating element disposed between said closures and within the annular space between the outer surface of said central tube and the inner surface of said first shell in such manner as to transfer heat inwardly through the walls of said central tube, means for electrically connecting one end of said first heating element to said central tube, a first contacting means exterior of said first shell for frictionally engaging and electrically contacting the well casing, electrically conductive means extending from the other end of said first heating element to said first contacting means, a second cylindrical shell having a diameter larger than that of said central tube but smaller than that of the well casing and affixed to said central tube adjacent the lower end thereof by a second set of spaced annular closures forming a fluid-tight seal between said central tube and said second shell,

a second electrical resistance heating element disposed between said closures and within the annular space between the outer surface of said central tube and the inner surface of said second shell in such manner as to transfer heat outwardly through the walls of said second shell, means for electrically connecting an end of said second heating element to said central tube, second contacting means exterior of said second shell for frictionally engaging and electrically contacting the well casing, electrically conductive means extending from the other end of said second heating element to said second contacting means and a well pump carried by said central tube between said first and second shells, said first heating element being electrically inductive so as to present a substantial impedance to the flow of alternating current therethrough and said second heating element being substantially non-inductive, the direct current resistance of said first heating element being substantially less than the direct current resistance of said second heating element and the inductive reactance of said first heating element at frequencies of 25-1000 cycles being substantially greater than the direct current resistance of said second heating element.

14. A device as defined in claim 13 wherein an electrical capacitor is electrically connected between said second contacting means and said second heating element, said capacitor having a capacitive reactance at 25-1000 cycles substantially less than the inductive reactance of said first heating element at said frequency.

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