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AEROSOL-GENERATING SYSTEM COMPRISING A CARTRIDGE WITH AN INTERNAL AIR FLOW PASSAGE

Abstract

A cartridge for an electrically heatable aerosol-generating system, the electrically heatable aerosol-generating system including: an aerosol-generating device including a device housing, an inductor coil positioned in the device housing, and a power supply connected to the inductor coil and configured to provide a high frequency oscillating current to the inductor coil, the cartridge being configured to be used with the aerosol-generating device, the cartridge including: a cartridge housing containing an aerosol-forming substrate, the cartridge housing having an internal surface surrounding an internal passage through which air can flow; and a susceptor element positioned to heat the aerosol-forming substrate, the susceptor element includes a first material having a Curie temperature that corresponds to a maximum temperature the susceptor element should have in use.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation application of and claims benefit under 35 U.S.C. § 120 to U.S. application Ser. No. 17/492,156, filed on Oct. 1, 2021 which is a continuation application of and claims benefit under 35 U.S.C. § 120 to U.S. application Ser. No. 15/311,992, filed on Nov. 17, 2016 (now U.S. Pat. No. 11,160,309), which is a U.S. national stage application of PCT/EP2015/060728, filed on May 14, 2015, and claims benefit of priority under 35 U.S.C. § 119 from EP 14169244.2, filed on May 21, 2014, the entire contents of each of which are incorporated herein by reference.

TECHNICAL FIELD
[0002] The disclosure relates to aerosol-generating systems that operate by heating an aerosol-forming substrate. In particular, the invention relates to aerosol-generating systems that comprise a device portion containing a power supply and a replaceable cartridge portion comprising the consumable aerosol-forming substrate.
DESCRIPTION OF THE RELATED ART
[0003] One type of aerosol-generating system is an electronic cigarette. Electronic cigarettes typically use a liquid aerosol-forming substrate which is vapourised to form an aerosol. An electronic cigarette typically comprises a power supply, a liquid storage portion for holding a supply of the liquid aerosol-forming substrate and an atomiser.
[0004] The liquid aerosol-forming substrate becomes exhausted in use and so needs to be replenished. The most common way to supply refills of liquid aerosol-forming substrate is in a cartomiser type cartridge. A cartomiser comprises both a supply of liquid substrate and the atomiser, usually in the form of an electrically operated resistance heater wound around a capillary material soaked in the aerosol-forming substrate. Replacing a cartomiser as a single unit has the benefit of being convenient for the user and avoids the need for the user to have to clean or otherwise maintain the atomiser.
[0005] However, it would be desirable to be able to provide a system that allows for refills of aerosol-forming substrate that are less costly to produce and are more robust that the cartomisers available today, while still being easy and convenient to use for consumers. In addition it would be desirable to provide a system that removes the need for soldered joints and that allows for a sealed device that is easy to clean.
SUMMARY
[0006] In a first aspect, there is provided a cartridge for use in an electrically heated aerosol-generating system, the electrically heated aerosol-generating system comprising an aerosol-generating device, the cartridge configured to be used with the device, wherein the device

comprises a device housing; an inductor coil positioned in the device housing; and a power supply connected to the inductor coil and configured to provide a high frequency oscillating current to the inductor coil; the cartridge comprising a cartridge housing containing an aerosol-forming substrate, the housing having an internal surface surrounding an internal passage through which air can flow; and a susceptor element positioned to heat the aerosol-forming substrate.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Embodiments of a system in accordance with the disclosure will now be described in detail, by way of example only, with reference to the accompanying drawings, in which:

[0008] FIG. **1** is a schematic illustration of a first embodiment of an aerosol-generating system, using a flat spiral inductor coil;

[0009] FIG. **2** shows the cartridge of FIG. **1**;

[0010] FIG. **3** shows the inductor coil of FIG. **1**;

[0011] FIG. **4** is a schematic illustration of a second embodiment;

[0012] FIG. **5** is a schematic illustration of a third embodiment;

[0013] FIG. **6** is an end view of the cartridge of FIG. **5**;

[0014] FIG. **7** shows the inductor coil and core of FIG. **5**;

[0015] FIG. **8**A is a first example of a driving circuit for generating the high frequency signal for an inductor coil; and

[0016] FIG. **8**B is a second example of a driving circuit for generating the high frequency signal for an inductor coil.

DETAILED DESCRIPTION

[0017] Advantageously, at least a portion of the internal surface of the housing is fluid permeable. As used herein a “fluid permeable” element means an element that allowing liquid or gas to permeate through it. The housing may have a plurality of openings formed in it to allow fluid to permeate through it. In particular, the housing allows the aerosol-forming substrate, in either gaseous phase or both gaseous and liquid phase, to permeate through it.

[0018] In operation a high frequency oscillating current is passed through the flat spiral inductor coil to generate an alternating magnetic field that induces a voltage in the susceptor element. The induced voltage causes a current to flow in the susceptor element and this current causes Joule heating of the susceptor that in turn heats the aerosol-forming substrate. If the susceptor element is ferromagnetic, hysteresis losses in the susceptor element may also generate heat. The vapourised aerosol-forming substrate can pass through the susceptor element and subsequently cool to form an aerosol delivered to a user.

[0019] This arrangement using inductive heating has the advantage that no electrical contacts need be formed between the cartridge and the device. And the heating element, in this case the susceptor element, need not be electrically joined to any other components, eliminating the need for solder or other bonding elements. Furthermore, the coil is provided as part of the device making it possible to construct a cartridge that is simple, inexpensive and robust. Cartridges are typically disposable articles produced in much larger numbers than the devices with which they operate. Accordingly reducing the cost of cartridges, even if it requires a more expensive device, can lead to significant cost savings for both manufacturers and consumers.

[0020] As used herein, a high frequency oscillating current means an oscillating current having a frequency of between 500 kHz and 30 MHz. The high frequency oscillating current may have a frequency of between 1 and 30 MHz, preferably between 1 and 10 MHz and more preferably between 5 and 7 MHz.

[0021] The provision of an internal passage within the cartridge for airflow allows for a system that

is compact. It also allows the system to be made symmetrical and balanced which is advantageous when the system is a handheld system. An internal passage for air flow also minimises heat losses from the device and allows the housing of the device and cartridge to be easily maintained at a temperature than is comfortable to hold. Vapourised aerosol-forming substrate in the air flow can cool within the internal passage and form an aerosol.
[0022] The aerosol-forming substrate may be held in an annular space surrounding the internal passage. The cartridge may have a generally cylindrical shape and may have any desired cross-section, such as circular, hexagonal, octagonal or decagonal.
[0023] As used herein, a “susceptor element” means a conductive element that heats up when subjected to a changing magnetic field. This may be the result of eddy currents induced in the susceptor element and/or hysteresis losses. Possible materials for the susceptor elements include graphite, molybdenum, silicon carbide, stainless steels, niobium, aluminium and virtually any other conductive elements. Advantageously the susceptor element is a ferrite element. The material and the geometry for the susceptor element can be chosen to provide a desired electrical resistance and heat generation. The susceptor element may comprise, for example, a mesh, flat spiral coil, fibres or a fabric.
[0024] Advantageously, the susceptor element is in contact with the aerosol-forming substrate. The susceptor element may form part of or all of the internal surface. The susceptor element may advantageously be fluid permeable.
[0025] The susceptor element may be provided as a sheet that extends across an opening in the cartridge housing. The susceptor element may extend around an internal or external perimeter of the cartridge housing.
[0026] Alternatively, the susceptor element may comprise a capillary wick that extends across the internal passage of the cartridge. The wick may comprise a plurality of fibres.
[0027] Advantageously, the susceptor element has a relative permeability between 1 and 40000. When a reliance on eddy currents for a majority of the heating is desirable, a lower permeability material may be used, and when hysteresis effects are desired then a higher permeability material may be used. Preferably, the material has a relative permeability between 500 and 40000. This provides for efficient heating.
[0028] The material of the susceptor element may be chosen because of its Curie temperature. Above its Curie temperature a material is no longer ferromagnetic and so heating due to hysteresis losses no longer occurs. In the case the susceptor element is made from one single material, the Curie temperature may correspond to a maximum temperature the susceptor element should have (that is to say the Curie temperature is identical with the maximum temperature to which the susceptor element should be heated or deviates from this maximum temperature by about 1-3%). This reduces the possibility of rapid overheating.
[0029] If the susceptor element is made from more than one material, the materials of the susceptor element can be optimized with respect to further aspects. For example, the materials can be selected such that a first material of the susceptor element may have a Curie temperature which is above the maximum temperature to which the susceptor element should be heated. This first material of the susceptor element may then be optimized, for example, with respect to maximum heat generation and transfer to the aerosol-forming substrate to provide for an efficient heating of the susceptor on one hand. However, the susceptor element may then additionally comprise a second material having a Curie temperature which corresponds to the maximum temperature to which the susceptor should be heated, and once the susceptor element reaches this Curie temperature the magnetic properties of the susceptor element as a whole change. This change can be detected and communicated to a microcontroller which then interrupts the generation of AC power until the temperature has cooled down below the Curie temperature again, whereupon AC power generation can be resumed.
[0030] The majority of the cartridge housing is preferably a rigid housing comprising a material

that is impermeable to liquid. As used herein "rigid housing" means a housing that is self-supporting.

[0031] The aerosol-forming substrate is a substrate capable of releasing volatile compounds that can form an aerosol. The volatile compounds may be released by heating the aerosol-forming substrate. The aerosol-forming substrate may be solid or liquid or comprise both solid and liquid components.

[0032] The aerosol-forming substrate may comprise plant-based material. The aerosol-forming substrate may comprise tobacco. The aerosol-forming substrate may comprise a tobacco-containing material containing volatile tobacco flavour compounds, which are released from the aerosol-forming substrate upon heating. The aerosol-forming substrate may alternatively comprise a non-tobacco-containing material. The aerosol-forming substrate may comprise homogenised plant-based material. The aerosol-forming substrate may comprise homogenised tobacco material. The aerosol-forming substrate may comprise at least one aerosol-former. An aerosol-former is any suitable known compound or mixture of compounds that, in use, facilitates formation of a dense and stable aerosol and that is substantially resistant to thermal degradation at the temperature of operation of the system. Suitable aerosol-formers are well known in the art and include, but are not limited to: polyhydric alcohols, such as triethylene glycol, 1,3-butanediol and glycerine; esters of polyhydric alcohols, such as glycerol mono-, di- or triacetate; and aliphatic esters of mono-, di- or polycarboxylic acids, such as dimethyl dodecanedioate and dimethyl tetradecanedioate. Preferred aerosol formers are polyhydric alcohols or mixtures thereof, such as triethylene glycol, 1,3-butanediol and, most preferred, glycerine. The aerosol-forming substrate may comprise other additives and ingredients, such as flavourants.

[0033] The aerosol-forming substrate may be adsorbed, coated, impregnated or otherwise loaded onto a carrier or support. In one example, the aerosol-forming substrate is a liquid substrate held in capillary material. The capillary material may have a fibrous or spongy structure. The capillary material preferably comprises a bundle of capillaries. For example, the capillary material may comprise a plurality of fibres or threads or other fine bore tubes. The fibres or threads may be generally aligned to convey liquid to the heater. Alternatively, the capillary material may comprise sponge-like or foam-like material. The structure of the capillary material forms a plurality of small bores or tubes, through which the liquid can be transported by capillary action. The capillary material may comprise any suitable material or combination of materials. Examples of suitable materials are a sponge or foam material, ceramic- or graphite-based materials in the form of fibres or sintered powders, foamed metal or plastics materials, a fibrous material, for example made of spun or extruded fibres, such as cellulose acetate, polyester, or bonded polyolefin, polyethylene, terylene or polypropylene fibres, nylon fibres or ceramic. The capillary material may have any suitable capillarity and porosity so as to be used with different liquid physical properties. The liquid has physical properties, including but not limited to viscosity, surface tension, density, thermal conductivity, boiling point and vapour pressure, which allow the liquid to be transported through the capillary material by capillary action. The capillary material may be configured to convey the aerosol-forming substrate to the susceptor element. The capillary material may extend into interstices in the susceptor element.

[0034] The susceptor element may be provided on a wall of the cartridge housing that is configured to be positioned adjacent the inductor coil when the cartridge housing is engaged with the device housing. In use, it is advantageous to have the susceptor element close to the inductor coil in order to maximise the voltage induced in the susceptor element.

[0035] In a second aspect, there is provided an electrically heated aerosol-generating system comprising an aerosol-generating device and a cartridge according to the first aspect, the device comprising: a device housing; an inductor coil positioned in the device housing; and a power supply connected to the inductor coil and configured to provide a high frequency oscillating current to the inductor coil; wherein, in use, a magnetic field generated by the inductor coil causes the

generation of heat in the susceptor material in the cartridge.
[0036] An airflow passage may be provided between the inductor coil and the susceptor element when the cartridge housing is engaged with the device housing. Vapourised aerosol-forming substrate may be entrained in the air flowing in the airflow passage, which subsequently cools to form an aerosol.
[0037] The device housing may define a cavity for receiving at least a portion of the cartridge when the device housing is engaged with the cartridge housing, wherein the inductor coil is positioned within, around or adjacent to the cavity. The inductor coil may be positioned outside of the cartridge when the cartridge is received in the cavity. The inductor coil may surround the cartridge when the cartridge is received in the cavity. The inductor coil may be shaped to conform to the internal surface of the cavity.
[0038] Alternatively, the inductor coil may be within the cavity when the cartridge is received in the cavity. In some embodiments, the inductor coil is within the internal passage when the cartridge housing is engaged with the device housing.
[0039] The device housing may comprise a main body and a mouthpiece portion. The cavity may be in the main body and the mouthpiece portion may have an outlet through which aerosol generated by the system can be drawn into a user's mouth. The inductor coil may be in the mouthpiece portion or in the main body.
[0040] Alternatively a mouthpiece portion may be provided as part of the cartridge. As used herein, the term mouthpiece portion means a portion of the device or cartridge that is placed into a user's mouth in order to directly inhale an aerosol generated by the aerosol-generating system. The aerosol is conveyed to the user's mouth through the mouthpiece.
[0041] The device may comprise a single inductor coil or a plurality of inductor coils. The inductor coil or coils may be helical coils of flat spiral coils. The inductor coil may be wound around a ferrite core. As used herein a “flat spiral coil” means a coil that is generally planar coil wherein the axis of winding of the coil is normal to the surface in which the coil lies. However, the term “flat spiral coil” as used herein covers coils that are planar as well as flat spiral coils that are shaped to conform to a curved surface. The use of a flat spiral coil allows for the design of a compact device, with a simple design that is robust and inexpensive to manufacture. The coil can be held within the device housing and need not be exposed to generated aerosol so that deposits on the coil and possible corrosion can be prevented. The use of a flat spiral coil also allows for a simple interface between the device and a cartridge, allowing for a simple and inexpensive cartridge design. The flat spiral inductor can have any desired shape within the plane of the coil. For example, the flat spiral coil may have a circular shape or may have a generally oblong shape.
[0042] The inductor coil may have a shape matching the shape of the susceptor element. The coil may have a diameter of between 5 mm and 10 mm.
[0043] The system may further comprise electric circuitry connected to the inductor coil and to an electrical power source. The electric circuitry may comprise a microprocessor, which may be a programmable microprocessor, a microcontroller, or an application specific integrated chip (ASIC) or other electronic circuitry capable of providing control. The electric circuitry may comprise further electronic components. The electric circuitry may be configured to regulate a supply of current to the coil. Current may be supplied to the inductor coil continuously following activation of the system or may be supplied intermittently, such as on a puff by puff basis. The electric circuitry may advantageously comprise DC/AC inverter, which may comprise a Class-D or Class-E power amplifier.
[0044] The system advantageously comprises a power supply, typically a battery such as a lithium iron phosphate battery, within the main body of the housing. As an alternative, the power supply may be another form of charge storage device such as a capacitor. The power supply may require recharging and may have a capacity that allows for the storage of enough energy for one or more smoking experiences. For example, the power supply may have sufficient capacity to allow for the

continuous generation of aerosol for a period of around six minutes, corresponding to the typical time taken to smoke a conventional cigarette, or for a period that is a multiple of six minutes. In another example, the power supply may have sufficient capacity to allow for a predetermined number of puffs or discrete activations of the inductor coil.

[0045] The system may be an electrically operated smoking system. The system may be a handheld aerosol-generating system. The aerosol-generating system may have a size comparable to a conventional cigar or cigarette. The smoking system may have a total length between approximately 30 mm and approximately 150 mm. The smoking system may have an external diameter between approximately 5 mm and approximately 30 mm.

[0046] Features described in relation to one aspect may be applied to other aspects of the disclosure. In particular advantageous or optional features described in relation to the first aspect of the disclosure may be applied to the second aspect of the invention.

[0047] The embodiments shown in the figures all rely on inductive heating. Inductive heating works by placing an electrically conductive article to be heated in a time varying magnetic field. Eddy currents are induced in the conductive article. If the conductive article is electrically isolated the eddy currents are dissipated by Joule heating of the conductive article. In an aerosol-generating system that operates by heating an aerosol-forming substrate, the aerosol-forming substrate is typically not itself sufficiently electrically conductive to be inductively heated in this way. So in the embodiments shown in the figures a susceptor element is used as the conductive article that is heated and the aerosol-forming substrate is then heated by the susceptor element by thermal conduction, convention and/or radiation. If a ferromagnetic susceptor element is used, heat may also be generated by hysteresis losses as the magnetic domains are switched within the susceptor element.

[0048] The embodiments described each use an inductor coil to generate a time varying magnetic field. The inductor coil is designed so that it does not undergo significant Joule heating. In contrast the susceptor element is designed so that there is significant Joule heating of the susceptor.

[0049] FIG. **1** is a schematic illustration of an aerosol-generating system in accordance with a first embodiment. The system comprises device **100** and a cartridge **200**. The device comprises main housing **101** (also referred to as a device housing **101** herein) containing a lithium iron phosphate battery **102** and control electronics **104**. The main housing **101** also defines a cavity **112** into which the cartridge **200** is received. The device also includes a mouthpiece portion **120** including an outlet **124**. The mouthpiece portion is connected to the main housing **101** by a hinged connection in this example, but any kind of connection may be used, such as a snap fitting or a screw fitting. Air inlets **122** are defined between the mouthpiece portion **120** and the main housing **101** when the mouthpiece portion is in a closed position, as shown in FIG. **1**.

[0050] Within the device housing **101** (also referred to as a main housing **101** herein), in the sidewalls of the cavity **112**, are flat spiral inductor coils **110**. The coils **110** are formed by stamping or cutting a spiral coil from a sheet of copper. One of the coils **110** is more clearly illustrated in FIG. **3**. If the device housing **101** has a generally circular cross-section, the coils **110** can be shaped to conform to the curved shape of the device housing **101**. The coils **110** are positioned on either side of the cavity and produce a magnetic field that extends within the cavity.

[0051] The cartridge **200** comprises a cartridge housing **204** holding a capillary material and filled with liquid aerosol-forming substrate. The cartridge **200** of FIG. **1** has a hollow cylindrical shape as more clearly shown in FIG. **2**. The cartridge housing **204** is mostly liquid impermeable. An interior surface **212** of the cartridge **200**, i.e. a surface surrounding the internal passageway **216**, comprises a fluid permeable susceptor element **210**, in this example a ferrite mesh. The ferrite mesh may line the entire interior surface of the cartridge or only a portion of the interior surface of the cartridge as shown in FIG. **1**. The aerosol-forming substrate can form a meniscus in the interstices of the mesh. Another option for the susceptor is a graphite fabric, having an open mesh structure.

[0052] When the cartridge **200** is engaged with the device and is received in the cavity **112**, the susceptor element **210** is positioned within the magnetic field generated by the flat spiral coils **110**. The cartridge **200** may include keying features to ensure that it cannot be inserted into the device incorrectly.

[0053] In use, a user puffs on the mouthpiece portion **120** to draw air though the air inlets **164** through the central passageway of the cartridge, past the susceptor element **262**, into the mouthpiece portion **120** and out of the outlet **124** into the user's mouth. When a puff is detected, the control electronics provide a high frequency oscillating current to the coils **110**. This generates an oscillating magnetic field. The oscillating magnetic field passes through the susceptor element, inducing eddy currents in the susceptor element. The susceptor element heats up as a result of Joule heating and as a result of hysteresis losses in the susceptor element, reaching a temperature sufficient to vapourise the aerosol-forming substrate close to the susceptor element. The vapourised aerosol-forming substrate is entrained in the air flowing from the air inlets to the air outlet, through the interior passageway **216** and cools to form an aerosol within the mouthpiece portion before entering the user's mouth. The control electronics supplies the oscillating current to the coil for a predetermined duration, in this example five seconds, after detection of a puff and then switches the current off until a new puff is detected.

[0054] It can be seen that the cartridge has a simple and robust design, which can be inexpensively manufactured as compared to the cartomisers available on the market. The use of a hollow cartridge allows for a short overall length for the system, as the vapour cools within the hollow space **202** defined by the cartridge, e.g., as shown in FIG. **1**.

[0055] FIG. **4** illustrates a second embodiment. Only the front end of the system is shown in FIG. **4** as the same battery and control electronics as shown in FIG. **1** can be used, including the puff detection mechanism. The cartridge **200** shown in FIG. **4** is identical to that shown in FIG. **1**. However the device of FIG. **4** has a different configuration that includes a flat spiral inductor coil **132** on a support blade **136** that extends into the central passageway **216** of the cartridge to generate an oscillating magnetic field close to the susceptor element **210**. The operation of the embodiment of FIG. **4** is the same as that of FIG. **1**.

[0056] FIG. **5** illustrates a third embodiment. Only the front end of the system is shown in FIG. **5** as the same battery and control electronics as shown in FIG. **1** can be used, including the puff detection mechanism.

[0057] The device of FIG. **5** is a similar to the device of FIG. **1** in that the housing **150** of the device defines a cavity into which the cartridge **250** is received. The device also includes a mouthpiece portion **120** including an outlet **124**. The mouthpiece portion is connected to the main housing **101** by a hinged connection as in FIG. **1**. Air inlets **154** are defined in the main body **150**. At the base of the cavity there is a helical coil **152** wound around a C-shaped ferrite core **153**. The C-shaped core is oriented so that a magnetic field generated by the coil **152** extends into the cavity. FIG. **7** shows the core and coil assembly alone, with the magnetic field pattern shown in dotted line.

[0058] The cartridge of FIG. **5** is shown in an end view in FIG. **6**. The cartridge housing **250** has a cylindrical shape with a central passageway **256** through it as in FIGS. **1** and **2**. The aerosol-forming substrate is held in the annular space surrounding the central passageway, and, as before may be held in a capillary element within the housing **250**. A capillary wick **252** is provided at one end of the cartridge, spanning the central passageway **256**. The capillary wick **252** is formed from ferrite fibres and acts both as a wick for the aerosol-forming substrate and as a susceptor that is inductively heated by the coil **152**.

[0059] In use, aerosol forming substrate is drawn into the ferrite wick **252**. When a puff is detected, the coil **152** is activated and an oscillating magnetic field is produced. The changing magnetic flux across the wick induces eddy currents in the wick and hysteresis losses, causing it to heat up, vapourising the aerosol-forming substrate in the wick. The vapourised aerosol-forming substrate is entrained in air being drawn through the system from the air inlets **154** to the outlet **124** by a user

puffing on the mouthpiece portion. The air flows through the internal passageway **256**, which acts as an aerosol-forming chamber, cooling the air and vapour as it travels to the outlet **124**.
[0060] All of the described embodiments may be driven by the essentially the same electronic circuitry **104**. FIG. **8**A illustrates a first example of a circuit used to provide a high frequency oscillating current to the inductor coil, using a Class-E power amplifier. As can be seen from FIG. **8**A, the circuit includes a Class-E power amplifier including a transistor switch **1100** comprising a Field Effect Transistor (FET) **1110**, for example a Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET), a transistor switch supply circuit indicated by the arrow **1120** for supplying the switching signal (gate-source voltage) to the FET **1110**, and an LC load network **1130** comprising a shunt capacitor C**1** and a series connection of a capacitor C**2** and inductor L**2**. The DC power source, which comprises the battery **101**, includes a choke L**1**, and supplies a DC supply voltage. Also shown in FIG. **16**A is the ohmic resistance R representing the total ohmic load **1140**, which is the sum of the ohmic resistance R.sub.Coil of the inductor coil, marked as L**2**, and the ohmic resistance R.sub.Load of the susceptor element.
[0061] Due to the very low number of components the volume of the power supply electronics can be kept extremely small. This extremely small volume of the power supply electronics is possible due to the inductor L**2** of the LC load network **1130** being directly used as the inductor for the inductive coupling to the susceptor element, and this small volume allows the overall dimensions of the entire inductive heating device to be kept small.
[0062] While the general operating principle of the Class-E power amplifier is known and described in detail in the already mentioned article “Class-E RF Power Amplifiers”, Nathan O. Sokal, published in the bimonthly magazine QEX, edition January/February 2001, pages 9-20, of the American Radio Relay League (ARRL), Newington, CT, U.S.A., some general principles will be explained in the following.
[0063] Let us assume that the transistor switch supply circuit **1120** supplies a switching voltage (gate-source voltage of the FET) having a rectangular profile to FET **1110**. As long as FET **1321** is conducting (in an “on”-state), it essentially constitutes a short circuit (low resistance) and the entire current flows through choke L**1** and FET **1110**. When FET **1110** is non-conducting (in an “off”-state), the entire current flows into the LC load network, since FET **1110** essentially represents an open circuit (high resistance). Switching the transistor between these two states inverts the supplied DC voltage and DC current into an AC voltage and AC current.
[0064] For efficiently heating the susceptor element, as much as possible of the supplied DC power is to be transferred in the form of AC power to inductor L**2** and subsequently to the susceptor element which is inductively coupled to inductor L**2**. The power dissipated in the susceptor element (eddy current losses, hysteresis losses) generates heat in the susceptor element, as described further above. In other words, power dissipation in FET **1110** must be minimized while maximizing power dissipation in the susceptor element.
[0065] The power dissipation in FET **1110** during one period of the AC voltage/current is the product of the transistor voltage and current at each point in time during that period of the alternating voltage/current, integrated over that period, and averaged over that period. Since the FET **1110** must sustain high voltage during a part of that period and conduct high current during a part of that period, it must be avoided that high voltage and high current exist at the same time, since this would lead to substantial power dissipation in FET **1110**. In the “on-” state of FET **1110**, the transistor voltage is nearly zero when high current is flowing through the FET. In the “off-” state of FET **1110**, the transistor voltage is high but the current through FET **1110** is nearly zero.
[0066] The switching transitions unavoidably also extend over some fractions of the period. Nevertheless, a high voltage-current product representing a high power loss in FET **1110** can be avoided by the following additional measures. Firstly, the rise of the transistor voltage is delayed until after the current through the transistor has reduced to zero. Secondly, the transistor voltage returns to zero before the current through the transistor begins to rise. This is achieved by load

network **1130** comprising shunt capacitor C**1** and the series connection of capacitor C**2** and inductor L**2**, this load network being the network between FET **1110** and the load **1140**. Thirdly, the transistor voltage at turn-on time is practically zero (for a bipolar-junction transistor "BJT" it is the saturation offset voltage Vo). The turning-on transistor does not discharge the charged shunt capacitor C**1**, thus avoiding dissipating the shunt capacitor's stored energy. Fourthly, the slope of the transistor voltage is zero at turn-on time. Then, the current injected into the turning-on transistor by the load network rises smoothly from zero at a controlled moderate rate resulting in low power dissipation while the transistor conductance is building up from zero during the turn-on transition. As a result, the transistor voltage and current are never high simultaneously. The voltage and current switching transitions are time-displaced from each other. The values for L**1**, C**1** and C**2** can be chosen to maximize the efficient dissipation of power in the susceptor element.

[0067] Although a Class-E power amplifier is preferred for most systems in accordance with the disclosure, it is also possible to use other circuit architectures. FIG. **8**B illustrates a second example of a circuit used to provide a high frequency oscillating current to the inductor coil, using a Class-D power amplifier. The circuit of FIG. **8**B comprises the battery **101** connected to two transistors **1210**, **1212**. Two switching elements **1220**, **1222** are provided for switching two transistors **1210**, **1212** on and off. The switches are controlled at high frequency in a manner so as to make sure that one of the two transistors **1210**, **1212** has been switched off at the time the other of the two transistors is switched on. The inductor coil is again indicated by L**2** and the combined ohmic resistance of the coil and the susceptor element indicated by R. the values of C**1** and C**2** can be chosen to maximize the efficient dissipation of power in the susceptor element.

[0068] The susceptor element can be made of a material or of a combination of materials having a Curie temperature which is close to the desired temperature to which the susceptor element should be heated. Once the temperature of the susceptor element exceeds this Curie temperature, the material changes its ferromagnetic properties to paramagnetic properties. Accordingly, the energy dissipation in the susceptor element is significantly reduced since the hysteresis losses of the material having paramagnetic properties are much lower than those of the material having the ferromagnetic properties. This reduced power dissipation in the susceptor element can be detected and, for example, the generation of AC power by the DC/AC inverter may then be interrupted until the susceptor element has cooled down below the Curie temperature again and has regained its ferromagnetic properties. Generation of AC power by the DC/AC inverter may then be resumed again.

[0069] Other cartridge designs incorporating a susceptor element in accordance with this disclosure can now be conceived by one of ordinary skill in the art. For example, the cartridge may include a mouthpiece portion and may have any desired shape. Furthermore, a coil and susceptor arrangement in accordance with the disclosure may be used in systems of other types to those already described, such as humidifiers, air fresheners, and other aerosol-generating systems.

[0070] The exemplary embodiments described above illustrate but are not limiting. In view of the above discussed exemplary embodiments, other embodiments consistent with the above exemplary embodiments will now be apparent to one of ordinary skill in the art.

Claims

1. A cartridge for an electrically heatable aerosol-generating system, the electrically heatable aerosol-generating system comprising: an aerosol-generating device comprising a device housing, an inductor coil positioned in the device housing, and a power supply connected to the inductor coil and configured to provide a high frequency oscillating current to the inductor coil, the cartridge being configured to be used with the aerosol-generating device, the cartridge comprising: a cartridge housing containing an aerosol-forming substrate, the cartridge housing having an internal surface surrounding an internal passage through which air can flow; and a susceptor element positioned to heat the aerosol-forming substrate, wherein the susceptor element comprises a first material having a Curie temperature that corresponds to a maximum temperature the susceptor element should have in use.

2. The cartridge according to claim 1, wherein the susceptor element is made from a single material, the single material being the first material.

3. The cartridge according to claim 1, wherein susceptor element further comprises at least a second material.

4. The cartridge according to claim 3, wherein the second material is a material having a Curie temperature that is above the maximum temperature.

5. The cartridge according to claim 1, wherein at least a portion of the internal surface of the cartridge housing is fluid permeable.

6. The cartridge according to claim 1, wherein the susceptor element forms part or all of the internal surface.

7. The cartridge according to claim 1, wherein the susceptor element further comprises a mesh, flat spiral coil, interior foil, fibres, fabric, or rod.

8. The cartridge according to claim 1, wherein the susceptor element is fluid permeable.

9. The cartridge according to claim 1, wherein the susceptor element is provided as a sheet that extends across an opening in the cartridge housing.

10. The cartridge according to claim 1, wherein the susceptor element further comprises a wick extending across the internal passage.

11. An electrically heatable aerosol-generating system comprising an aerosol-generating device and a cartridge according to claim 1, the aerosol-generating device comprising: a device housing; an inductor coil positioned in the device housing; and a power supply connected to the inductor coil and configured to provide a high frequency oscillating current to the inductor coil, wherein, in use, a magnetic field generated by the inductor coil causes the generation of heat in the susceptor element in the cartridge.

12. The electrically heatable aerosol-generating system according to claim 11, further comprising a microcontroller configured to interrupt a supply of oscillating current to the inductor coil in response to a detected change in magnetic properties of the susceptor element when the susceptor element reaches a Curie temperature of the first material, the detected change in magnetic properties being communicated to the microcontroller.

13. The electrically heatable aerosol-generating system according to claim 11, wherein the device housing defines a cavity configured to receive at least a portion of the cartridge, and wherein the inductor coil is positioned within, around, or adjacent to the cavity.

14. The electrically heatable aerosol-generating system according to claim 13, wherein the inductor coil is positioned outside of the cartridge when the cartridge is received in the cavity.

15. The electrically heatable aerosol-generating system according to claim 14, wherein the inductor coil surrounds the cartridge when the cartridge is received in the cavity.

16. The electrically heatable aerosol-generating system according to claim 13, wherein the inductor coil is within the internal passage when the cartridge is received in the cavity.

17. The electrically heatable aerosol-generating system according to claim 11, wherein the system is a handheld smoking system.

18. A method of operating the electrically heatable aerosol-generating system according to claim 11, the method comprising the steps of: supplying an oscillating current to the inductor coil from the power supply to cause the generation of heat in the susceptor element in the cartridge; detecting a reduction in the power dissipation of the susceptor element as result of a change in magnetic properties of the susceptor element when a temperature of the susceptor element reaches a Curie temperature of the first material of the susceptor element; and interrupting the supply of oscillating current to the inductor coil following the detecting step.
