Title: INDUCTION HEATING SYSTEM AND METHOD FOR HUMIDIFIER

Abstract: A humidifier includes: a container (20) to receive water; a heating element (22) formed of a ferrous material; a heating unit including an induction coil and a control circuit. The control circuit applies an alternating current (A-C) current to the coil if a metal inductance of the coil and heating circuit is within a predetermined range, and a gap separating the heating element from the induction coil, wherein the heating element is heated by an electromagnetic coupling with the induction coil.
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
INDUCTION HEATING SYSTEM AND METHOD FOR HUMIDIFIER

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 60/780,368, filed March 9, 2006, incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Technical Field

[0003] The present invention relates to humidifiers, such as those used to introduce moisture into air flowing to a patient in a Continuous Positive Airway Pressure (CPAP) device. In particular, the invention relates to heating water in humidifier water tanks.

[0004] 2. Background

[0005] CPAP devices provide a continuous flow of positive pressure air to the breathing passages of a patient suffering from sleep apnea. The positive pressure assists the breathing of the sleeping patient. CPAP devices often include humidifiers to add moisture to the air supplied to the patient. Moisture reduces the tendency of the breathing passages and skin of the patient to dry out.

[0006] A humidifier in a CPAP device typically includes a water tank and a heating plate for the tank. The CPAP moves positive pressure air through the humidifier. The
air collects moisture as it flows over the surface of the water in the tank. The volume of moisture collected by the air depends on the temperature of the water. Generally, the warmer the water the greater the amount of moisture that evaporates into and is absorbed by the air.

[0007] A heating plate in a humidifier controls the temperature of the water in the tank. The heating plate conventionally includes a Joule heating element. The tank has a metal base at its bottom that sits on the heating plate. The Joule heating plate conducts heat to the metal plate which heats the water in the tank.

[0008] The conventional Joule heating plate and metal tank bottom introduce thermal inefficiencies and losses as heat passes across multiple thermal impedances, e.g., heating plates, the gap between the plate and tank base, and the base to water. These impedances reduce the rate of heat flow. To compensate for the impedances, additional energy is applied in a conventional Joule heating unit. Further, each thermal impedance is a potential source of humidifier unit-to-unit variation which must be accommodated to ensure a predictable level of humidification from all units.

[0009] Existing humidifiers with Joule heating plates typically address thermal inefficiencies in one or more of the following ways:

[0010] i. The heater element and power delivery system are designed to deliver up to 85W (Watts) of heat. While about 80 watts is required to initially heat 350 ml
(milliliters) of water from 20°C to 60°C within 20
minutes, only 30 watts is required to maintain 10mg/l
(milligrams of water per liter of air) of humidification
at an air flow of 60 lpm (liter per minute). In general,
more power is required initially to heat the volume of
water and then less power is required to maintain the
temperature and deliver the humidification.

[0011] ii. The interface between the metal heater plate
and the metal base is extremely flat to maximize the
contact surface area and minimize the thermal impedance
due to air gaps in the interface that would reduce heat
flow. Humidifier unit-to-unit thermal variations are
addressed by including a knob to control the humidity
level. By turning the knob, the user adjusts the heat
input to achieve the desired level of humidification and
thereby compensate for unit-to-unit thermal impedance
variations.
A humidifier has been developed comprising: a container to receive water; a heating element formed of a ferrous material; a heating unit including an induction coil and capacitor forming a resonant circuit and an control circuit, wherein the control circuit applies an alternating current (A-C) current at the resonant frequency to the coil if the inductance of the coil and heating circuit is within a predetermined range, and a gap separating the heating element from the induction coil, wherein the heating element is heated by an electromagnetic coupling with the induction coil. The humidifier may have an input connectable to a source of above-atmospheric air and an output for providing moisture laden air connectable to a conduit leading to a breathing passage of a patient.

The heating unit of the humidifier may include a ferrite core supporting the induction coil that is included in a resonance circuit comprising a capacitor in parallel with the induction coil and a switch operated by the control circuit, wherein the switch cyclically applies a power source to the resonance circuit. The heating element may be a metallic plate with at least one surface, such as heat transfer fins, in direct contact with water in the container. Moreover, the container may include a non-conductive and water proof coating over at least a bottom surface of the container. An induction coil in the humidifier induces a current in the heating element and the heating element warms due to the power dissipated by the heating element resistance. The induced
current is eddy currents at or near the surface of the heating element.

[0015] Some of the potential advantages for using induction heating as the heat source for humidifiers include: (i) the heating process is not based on thermal conduction through multiple interfaces and does not require intimate contact between the metal tub plate and heater element; (ii) greater permissible tolerances in the seating of the water tub on the humidifier; and (iii) efficient heating due to minimal heat loss due to few thermal impedances (in contrast, a Joule heating system has multiple thermal resistance interfaces that reduce efficiency and increase the input power required to achieve the desired temperature and level of humidification).

[0016] Potential disadvantages of induction heating as compared to the traditional Joule heating approach include: (i) induction heating requires a more complex analysis because the typical physical heating element geometries do not lend themselves to simple solutions of Maxwell's Equations. An exemplary approach is to derive a first order model of the heating element to aid in understanding induction heating in the system and then experimental bench testing of heating element designs to tune the heating system, and (ii) the temperature sensing is inside the humidifier tub and remote from the induction heating controller.

[0017] Additional advantages and features of the induction humidifier disclosed herein as compared to Joule heater
humidifiers include: intimate thermal contact is not required between a heater element in the chassis and metal plate in the tub; reduced cost due to an increased gap and wider tolerances between the tub and chassis; coating with plastic the underside surface of the metal plate in the tub to prevent water leaks and avoid exposure to users of hot metal surfaces; coating with plastic the chassis to avoid exposure to users of hot surfaces; increased power efficiency due to better power transfer; an induction heating power circuit that is compatible with low voltage, e.g., DC, and high voltage operation, e.g., AC; a humidity control signal applied as feedback to the power circuit (in contrast to a water temperature signal); a power control circuit for the heating element integrated with a flow generator alternating circuit (AC) power supply which results in shared common circuit components; minimal circuitry exclusively devoted to the humidifier heater (e.g., exclusive circuit may be a resonant inductor, resonant capacitor, MOSFET switch and feedback sensors); varying the MOSFET switch drive frequency may be used to extend the operating range of the supply voltage; the system can run off low voltage DC supplies or AC power; the control circuit may be a conventional low cost Zero Voltage Switching (ZVS) control circuit that is commonly used in power supplies technologies, the Error Amplifier used in conventional ZVS power supply control circuits can be used in a feedback control circuit to control the temperature or humidity. A further advantage is increased electrical safety as none of the electrical components need to be near the water.
Elements of the induction heating circuit and controller may include: a resonant circuit (such as a coil, capacitor and effective resistance of the metal heater plate, together with the MOSFET to supply-excitation); a resonant controller with zero voltage switching of a MOSFET switch that applies heating power to the induction heating element; a ferrite may be used for the coil to increase heating and power efficiency; the coil to heater plate gap is reduced, e.g., below two (2) millimeters (The is dependent upon the current flowing in the coil, i.e. the power in the circuit); minimizing the ferrous material near the coil apart from the metal heater plate to maximize efficiency.

The humidifier may be embodied in a Continuous Positive Airway Pressure (CPAP) device (or ventilators) that comprises: a flow generator having an output of above-atmospheric air flow; a water container and including an input to receive the above-atmospheric air flow and an output to pass moisture carrying above-atmospheric air to a conduit leading to a breathing passage of a patient; a ferrous heating element in the container and including at least one surface adapted to be exposed to water in the container; a platform including a support surface for the water container and housing a heating unit adjacent the support surface; the heating unit including an induction coil and an control circuit, wherein the heating element in the water container is separated by a gap from the induction coil wherein the heating element is heated by an electromagnetic coupling with the induction coil.
The humidifier may be used in a method for increasing humidity in a source of air being supplied to a breathing passage of a patient comprising: supplying the air to a water container such that the air absorbs moisture as the air flows over a surface of water in the container; outputting the moisture carrying air to a patient; heating the water in the container with a heating element, and inducing a current in the heating element by applying a changing electromagnetic field generated an induction coil, wherein the coil is separated by a gap from the heating element.

Further, the changing electromagnetic field may be generated by applying an alternating current to the induction coil by: cyclically applying a voltage source to the induction coil, charging a resonance capacitor and the current in the induction coil leading to energy storage in the induction coil and resonant capacitor while the voltage source is applied to the induction coil, wherein the capacitor is in parallel to the coil, and discharging the capacitor voltage into the coil and the coil current into the capacitor in a resonant circuit while the voltage source is turned off and not applied to the induction coil and capacitor. A period during which the voltage is applied to the induction coil may correspond to a period required to charge the coil current and capacitor voltage to a predetermined level, and a period during which the stored energy discharges into the resonant circuit effective resistance corresponds to a period required to fully discharge the capacitor then recharge it to its starting value to allow zero voltage switching. The cyclical application of the
voltage source may include transitions between applying the voltage source and discharging the stored energy and these transitions occur while substantially no voltage potential is present across the induction coil. This is known as zero voltage switching to those skilled in the art. The voltage source may be an alternating voltage source which is rectified to produce a DC (direct current) voltage source or a constant voltage source, such as a battery.
BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIGURE 1 is a perspective view of an exemplary CPAP device having a humidifier.

[0023] FIGURE 2A is a schematic diagram showing a side view of the humidifier including a tub and an underlying heater.

[0024] FIGURE 2B is schematic diagram of an underside view of the lower surfaces of the heating element.

[0025] FIGURE 3 is a series of charts showing the current and voltage cycle for the electronic circuit.

[0026] FIGURE 4 is a schematic diagram of a first exemplary electronic circuit for the heater.

[0027] FIGURES 5A and 5B are a schematic diagram of a second exemplary electronic circuit for the heater.

[0028] FIGURE 6 is a schematic diagram showing a side of an alternative humidifier including a tub and an underlying raised heating element.

[0029] FIGURE 7 is a schematic diagram showing a side of an alternative humidifier including a tub and an underlying diaphragm heating element.
[0030] FIGURE 8 is a schematic diagram showing a side of an alternative humidifier including a tub and a sleeve style diaphragm heating element.

[0031] FIGURE 9 is a schematic diagram of a CPAP system having temperature and/or humidification feedback.

[0032] FIGURE 10 is a chart showing a relationship between air tube length and air temperature along the tube for a CPAP system.
DETAILED DESCRIPTION OF ILLUSTRATED EMBODIMENTS

FIGURE 1 illustrates an exemplary CPAP system 10 that includes a flow generator 12 and a heated humidifier 14 adapted to be coupled to the flow generator. The flow generator, e.g., blower, provides a continuous stream of pressurized air, e.g., above-atmospheric air, to an air passage 16 connected to the humidifier. The pressurized air flows through the humidifier where it absorbs evaporated water. The moisture carrying air passes from an outlet 18 to a user interface 21 (Fig. 2), e.g. a face mask. The user interface generally supplies the air to a breathing passage of the patient wearing the user interface. The temperature of the water is controlled to regulate the humidity level of the air passing through the humidifier.

FIGURE 2A schematically shows the humidifier 14 which includes a tub 20, a heating element 22 and an induction resonance circuit 24. The heating element 22 may be a ferrous plate in the tub. The plate may be integrally molded to the bottom of the tub. Alternatively, the plate may be suspended slightly above the tub bottom to allow water to circulate across lower surfaces of the plate, as well as the upper surface of the plate. The heating element may include heat transfer features 23, e.g., metallic fins, to enhance the conduction of heat from the element to the water.

The tub 20 receives a volume of water, such as, several hundred milliliters, e.g., 200-500 ml. The inlet passage 16 and outlet 18 are in fluid communication with
an air chamber 19 above the water in the tub. Pressurized air from the flow generator 12 enters the tub air chamber from inlet passage 16. The air absorbs moisture through contact with the heated water within the tub 20, and flows through the outlet 18 to the patient via an air delivery conduit (shown by dotted lines) and a user interface 21.

[0037] The humidifier 14 may be structured such as the humidifier described in commonly-owned U.S. Provisional Patent Application No. 60/707,949 (Attorney Ref. 4398-435), entitled "Humidifier Tub For CPAP Device", filed August 15, 2005, the contents of which are incorporated in its entirety by reference herein. The humidifier chassis above the coil may be electrically and heat non-conductive to simplify electrical safety requirements. The tub material may be a material with low heat transfer, e.g., heat insulating, to reduce loss of heat through the tub walls.

[0038] The tub 20 sits on a platform 26 that may be formed as the top of a plastic enclosure 28. The enclosure houses the induction resonance circuit 24 that heats the heating element 22 in the tub. The upper surface of the platform may conform to receive the bottom of the tub 20. However, the upper platform surface and bottom of the tub need not be perfectly flat. The induction heating allows for gaps 31 between the platform and tub.

[0039] The heating element 22 may comprise a plate having various surface features to promote heat transfer from the plate to the water in the tub 20. Preferably, the
plate will have a geometry that positions hot spots of the plate near surfaces in contact with the water. To position plate hot spots rear the water, the plate may include perforations extending from a bottom surface and extending to a top surface of the plate. The plate perforations may be arranged as flutes to promote water circulation. The perforations allow hot water to flow upward through the plate due to heat convection. Perforations in the heating element 22 may be formed as slots through the element and extending, at least partially, radially outward from a center location of the slot. The heating element with perforations may be cold-formed, cast or sintered. The perforations may also be formed by punching through the heating element, after the element is initially formed.

[0040] When the tub is seated on the platform, the heating element 22 is proximate to an induction coil and ferrite assembly 30 mounted below the platform and within in the plastic enclosure 28. The heating element 22 may be formed of a magnetic metal material, such as iron or steel, and preferably is formed of sheet metal. The plastic enclosure 28 may be bonded to the ferrite assembly 30, such that plastic covers the surfaces of the ferrite core. The plastic enclosure supports the ferrite assembly and may prevent breakage of the assembly if the enclosure is dropped or otherwise hit with an impact force.

[0041] The heating element 22 is electromagnetically coupled to the induction coil and ferrite assembly 30 such that the assembly induces electrical current into
the heating element. The heating element is part of a magnetic path formed by the coil and ferrite assembly. During high frequency operation of the coil, the magnetic fields induced eddy currents on the surfaces of the heating element. These currents will heat the element.

[0042] The heating element 22 is electromagnetically coupled to the induction coil and ferrite assembly 30 such that the assembly induces electrical current into the heating element. The coil and ferrite assembly 30 are part of the induction resonance circuit 24 that also includes the heating element electromagnetically coupled to the coil 34, a power source 42, resonance capacitor 44, high frequency switch 46 and switch controller 48.

[0043] The switch controller operates the switch 46, a MOSFET switch, at a switching cycle. The switching frequency may be between 50kHz and 120kHz. The induction coil 34 is approximately 0.5mH, and the resonant capacitor 44 is 47nF in the alternating current embodiment shown in this application. During the first half of the switching cycle, energy is applied to and stored in the resonance circuit. During the second half of the cycle the stored energy is dissipated by the total resistance of the resonant circuit.

[0044] The resistive components of the circuit are primarily the wire resistance, coil resistance, core losses and the effective resistance of the heater plate. By configuring the resonant circuit such that the total resistance in the circuit is primarily due to the effective resistance of the metal heating plate 22 the
heating efficiency of the circuit can be made to be relatively high. The quality factor (Q) of the resonant circuit indicates the proportion of stored energy that is dissipated during each cycle. A low Q leads to poor eddy current induction and a high Q leads to poor energy dissipation. A Q of approx three leads to good energy dissipation in the heater plate.

The heating element 22 may be separated by an air gap 31 from the induction coil and ferrite-assembly. The gap between the coil and the heater metal plate determines the electromagnetic coupling and hence the effective resistance of the heater metal plate. Preferably, the gap may be less than two (2) to (3) millimeters to ensure acceptable heating performance, but the gap may be wider. The heating element may be in direct contact with the water in the tank, and need not contact the coil and ferrite assembly 30. There is no requirement for metal-to-metal contact between the tub and platform. The bottom of the tub 20 may be formed of plastic or coated by plastic to form a water tight seal.

The gap 31 between the induction coil 34 and heating element 22 affects the power transfer. A gap 31 of no more than a few millimeters (mm), e.g., 3 mm, between the induction coil and heating elements provides for good power transfer. The gap may be large enough to accommodate the plastic coatings on the tub 20 and enclosure 28, and gaps between the tub and platform. The gap also allows for generous tolerances in the manufacture of the platform and tub.
The heating element 22 may be formed of a suitable corrosion resistance ferrous metal material with a high permeability and low resistivity. Ferrous metal materials include, for example, iron and stainless steel, e.g., grade 412. In addition, the heating element should have good thermal conductivity to maximize the heat transfer rate to the water.

The water contact surface area of the heating element 22 may be maximized. Direct-contact between the heating element and water facilitates the transfer of heat to the water. The area of the heating element exposed to air and plastic should be minimized. Heat transfer fins 23 on the heating element provide good water contact surface area. For example, the heating element may be a metal disc attached to the bottom of the tub with heat transfer fins. Fins 23 on upper surface of the heating element may extend up into the water from the disc to maximize the water contact surface area. Heat is conducted rapidly from the metal disc to the metal fins.

FIGURE 2B is an underside view of the lower surfaces of the heating element 22. The heating element may be raised in the tub to increase the effective surface area of the element that is exposed to water. The lower surface of the heating element may be effectively raised by forming an annular recess 27 through which water may circulate. Water is heated by the exposed heating element surfaces of the recess 27. The recess 27 may be defined by a circular disc portion 29 of the heating element in the center of the recess and a ring portion 33 of the element at the periphery of the heating element.
The bottom surfaces of the disc 29 and ring 33 may be attached to the bottom of the tub. The bottom surfaces of the disc 29 and ring 33 may have cut-outs, be scalloped or otherwise have a surface that allows water to flow to and from the recess 27. In addition, the annular recess 27 reduces the surface area of the heating element in contact with the bottom of the tub 20. Only the lower surface of the ring and disc portions of the heating element contact the tub. Reducing the contact surface area of the heating element minimizes the conductive transfer of heat into the tub walls.

[0050] The recesses allow the raised lower surfaces of the heating element, as well as the upper surfaces, to heat water. The eddy currents tend to be concentrated on the upper and lower surfaces of the heating element near the annular recess 27. Further, the heating element 22 may be suspended in the water to provide water contact on all sides of the element. A few small support posts between the element and tub may suspend the element in the tub.

[0051] A temperature sensor 32 in the tub senses water temperature. Alternatively, the temperature sensor (32 in Fig. 6) may be on upper surface of the base and touching the underside of the metal heating element to measure plate temperature. A signal from the temperature sensor is transmitted to a controller 48 of the humidifier. In Figure 2, the sensors 32 are schematically shown with the control circuit 48 and may in practice be positioned in the tub, air flow 19 or wherever appropriate to monitor the water temperature and humidity of the air flow. The controller 48 may be included in the controller for the
CPAP system or in a controller dedicated to the humidifier. The controller 48 determines when to induce current into the heating element 22 based, at least in part, on the temperature or humidity signal from sensor 32. The controller also determines the frequency in order to control the power of the excitation applied to the coil 34.

[0052] The coil and ferrite assembly 30 includes a ferrite core 36 supporting the induction coil 34. The induction coil 34 may be wrapped around the ferrite core 36. Alternatively, the induction coil may be formed without a ferrite core, such as with an air core. The coil may be arranged in an oval adjacent and parallel to the platform 26. The coil may be a single winding wrapped around a ferrite tooth of the core, as is illustrated in Figure 2. Good power efficiency and low spurious electromagnetic signal emissions are achieved with a ferrite core and a minimum gap 31 between the coil and heating element 22.

[0053] The coil and core assembly 30 is included in the resonance circuit 24 comprising a capacitor 44 in parallel with the induction coil 34 and a switch 46 operated by the control circuit 48, wherein the switch cyclically applies a power source 42 to the resonance circuit. The heating element 22 is electromagnetically coupled to the coil and core assembly 30 and is thus included in the resonance circuit. The alternating current in the induction coil 34 induces a current in and on the heating element 22. The induction coil 34 may comprise stranded wires to minimize high frequency effects in the coil. The coils 34 may also be "Litz".
wire, especially if frequencies above 1000 Hertz (Hz) are in the coil. The heating element warms as the power is dissipated by the heating element resistance. The induced current may include eddy currents at or near the surface of the heating element.

[0054] The resonance circuit 24 provides induction heating of the heating element 22 by applying a high frequency AC current to the induction coil. The alternating current in the coil induces currents, e.g., eddy currents, in the heating element and especially on the surfaces of the heating element. Electrical current is provided to the coil by wires 38 connected to an direct current (DC) power supply 42 provided by the resonance circuit and switching element 46. The power supply 42 may include a chargeable battery.

[0055] The control circuit 48 cyclically turns-ON and OFF the switch 46 to cause the alternating current to be applied to the induction coil 34. The frequency at which the switch, e.g., a metal-oxide-silicon field effect transistor (MOSFET) is turned ON and OFF is determined by the controller. The switch 46 is turned ON and OFF to apply an alternating current to the resonance circuit 24. The control circuit receives signal inputs from sensors 32 regarding conditions such as water temperature and/or humidity in the air passing through the humidifier. The controller 48 determines when to heat the water in the tub by monitoring the temperature of the water and/or the air humidity. When the water is to be heated, the control circuit 48 applies a control cycle (see Fig. 3) to the switch 46 which in turn causes an A-C current to be
applied to the induction coil 34 to heat the heating element 22.

[0056] The parallel arrangement of the induction coil 34 and capacitor 44 together with the total resistance of the resonant circuit forms an inductance-capacitance-resistance (LCR) resonant circuit in which the voltage across the capacitor 44 (and hence the current in the coil) gradually increases after the switch is turned ON to complete the circuit with the battery 42. Similarly, the current in the coil gradually decreases after the switch is turned OFF in an oscillatory fashion at a resonant frequency. The capacitance of the capacitor 44 may be selected such that the desired resonant frequency is achieved. The transition of the switch from OFF to ON should occur when the voltage potential across the switch is zero(0) to minimize power losses. Alternatively, the capacitor may be in parallel with the MOSFET switch to form the resonant circuit.

[0057] The inductance of the LCR circuit 24 is dependant on the presence of the heating element. The inductance of the circuit 24 can be monitored to determine whether the tub is presence. The control circuit 24 can monitor the inductance of the circuit 24, e.g., the rate of voltage rise across the capacitor 44, to determine if the inductance is outside a predetermined acceptable range. If the inductance is outside the range, the controller may determine that the tub is not in place and not apply power to the coil.
FIGURE 3 shows an exemplary switch cycle (MOSFET gate voltage) in which the switch 46 (Fig. 2) is turned ON during a charge-up period 50 and turned OFF during a resonance period 52. The MOSFET switch allows for high frequency switching, e.g., at least 10 kHz and preferably 50 kHz to 120 kHz. The higher the frequency the lower the values of L and C required, but the higher the switching losses in the MOSFET. During the charge-up period 50, the control circuit 48 turns ON the switch and electrically connects the battery to the resonance circuit 24. As the capacitor is charged by the power source (period 50), the induction current 54 in the induction coil gradually increases. During the discharge period 52, the control circuit turns the switch OFF and disconnects the power supply from the coil and capacitor. During the OFF period 52, the current in the induction coil gradually decreases as the capacitor and coil discharge energy into the total resistance (which is primarily due to the heating element). The control circuit is designed such that switch 46 (Q1 in Figure 4) is turned ON at times when the voltage across the switch is near zero to ensure minimal power loss in the switch. When the switch is off, the drain source voltage 56 on the switch rises and falls as the voltage is discharged and then charged by the inductor current.

The heating element 22 is heated by induction heating. The heating element 22 and induction coil and ferrite assembly 30 operate together as a resonance transformer. The induction coil effectively forms the primary transformer winding and the heating element 22 forms a single turn secondary winding with a material and
geometry dependant load resistance. The alternating current in the induction coil induces eddy currents on the heating element. The induced eddy currents together with the effective resistance of the heating element heat the heating element. The effective resistance is due to the material properties of the heating element, such as resistivity and permeability, the geometrical configuration of the heating element, and the operating frequency of the heating drive circuitry.

[0060] The amount of energy stored (Estored) in the induction coil at the end of the charging period 50 is related to the ON time of switch Q1 (46), supply voltage 42 level (V) and the coil 34 and heating element combine inductance (L). via the following relationship:

\[ Estored = \frac{1}{2} LI^2 = \frac{1}{2} L \left( \frac{V}{L} t_{ON} \right)^2 = \frac{1}{2} L \left( \frac{2}{L} t_{ON} \right)^2 \]

[0062] where \( t_{ON} \) is the period during each cycle during which the switch Q1 is turned ON.

[0063] MOSFET Switch Q1 46 is turned OFF so that the resonance circuit 24 resonates at a resonant frequency corresponding to the cycle period, e.g., periods 50 and 52. The resonating induction coil produces a resonating magnetic field over the heating element that induces eddy currents on the element.

[0064] During charging (with the MOSFET switch ON), energy is stored in both the inductor (as current) and capacitor (as a voltage potential). The dominant energy storage
depends on the power supply voltage and circuit elements. For a low voltage power supply, e.g., a supply voltage of less than 30 volts, most of the energy stored during charging is in the inductor current. For a high voltage power supply, e.g., 110V to 240V AC, the inductor and capacitor share the energy storage during charging.

[0065] The eddy currents flow in a thin surface layer called the skin depth. The resistance of the skin depth and the eddy currents determine the power dissipation in the metal. The skin depth is determined by the operating frequency ($\omega$), resistivity (\(\rho\)) and permeability (\(\mu\)) of the heating plate as per the following equation:

\[
\delta = \sqrt{\frac{2\rho}{\mu\omega}}
\]

[0066] The skin depth, together with the resistivity and geometry of the heater plate material determine the effective resistance of the path traversed by the eddy current. The eddy current and resistance then set the power dissipated as heat in the heater plate.

[0067] FIGURE 4 is a schematic diagram of an induction resonance circuit having a direct current (DC) power supply 42. The controller 48 may include a hardware resonant controller integrated circuit (IC), a microcontroller or microprocessor 60 that monitors the sensors (32 in Fig. 2) and controls the MOSFET switch 46 (Q1). A power regulator circuit 47 provides a regulated power source for the controller IC 60. In Figure 4, the sensors are represented by the control input driven by
the sweep output of a trim potentiometer 45 powered from VCC to GND. The control input (NI) is a voltage source that provides a target value for the controller.

[0069] The schematic shown in Figure 4 is shown as operating in open loop which has no feedback control. The controller IC 60 also includes an error amplifier. Feedback may be included by using the error amplifier to compare a set point input from the user input to a measured humidity or heater plate temperature value to determine the required heater output.

[0070] If the sensor signals (as represented by trim pot 45) are beyond a predefined range and the controller determines that the tub is on the platform and filled with water, the controller applies the high frequency switch cycle to the MOSFET 46. When turned ON, the switch causes a current to flow from the battery 42, through the capacitor 44, the switch 46 and to ground. The current flow charges the capacitor 44 to a voltage which then forces an increase in the inductor current. When the switch 46 turns off, the inductor and capacitor 44 exchange energy at the resonant frequency which induces a current in the heating element 22. A zero crossing voltage detector transistor 47 detects when the voltage across the switch 46 is zero. The zero crossing signal may be used to determine when to change the switch 46 from OFF to ON.

[0071] FIGURES 5A and 5B together are a schematic diagram of an alternative induction resonance circuit 24 having an alternating current (AC) power supply 150. A
controller IC 152 provides control functions for the circuit 24. The AC power supply may be through a plug connection to a conventional home wall power socket. The AC power is rectified and filtered with a bridge and filtering inductor 154. Power is supplied to the main induction coil 156 and resonance capacitor 158 through a pair of MOSFET switches 160. The controller operates the MOSFET switches in the manner described above for Figures 3 and 4.

The rectified voltage from the AC power supply is applied to a power sensing path 162 and to initiate the IC controller. A voltage sensing circuit 164, is used by the controller to sense for rectified DC voltage and to determine the average maximum DV voltage. The voltage sensing circuit is divided into two parts: the mains peak voltage and the instant input voltage. The mains peak voltage signal controls the switch frequency to compensate for the output power. Increasing the duty cycle and/or the frequency "reduces the power level. The instant input voltage signal compensates for the current during each mains cycle to perform power factor correction (PFC). It is desired to achieve constant power despite changes in the input voltage level. The mains peak voltage 163 and the instant input voltage 165 are added together 167 to form the total control of the output power. The system can control and regulate the output power under varying mains voltage levels from 85V to 260V and control the current instantly to perform the PFC control. A diode 168 controls the upper limit of the dynamic power input range. A pulse width modulation (PWM) control loop includes a MOSFET switch 170 that controls
the frequency components of the rectified DC power applied to drive the controller and sensors. The PWM may be only used in the input voltage sensing circuit 164 to control the level of power. A PWM control loop may not be needed in the output control circuits which may only change the frequency to control the power output during low current when the MOSFET 170 is switched off resulting in low output power and a high frequency.

[0073] A thermistor temperature sensor 172 and/or a humidity sensor 174 generates signals 176 applied as feedback to the controller IC 152. The feedback signals 176 from the temperature and/or humidity sensors are applied to control a temperature power cutoff switch 178. The switch 178 provides a signal to the controller IC 152 indicative of the temperature and/or humidity of the air flow to the user. The IC 152 compares the indicated temperature and/or humidity to a desired temperature/humidity level (such as using the comparison function of the ICs error amplifier) to determine whether the heating element in the tub should be heated.

[0074] A secondary power supply 180 may also provide current to the coils 156. The secondary power supply may be battery 182 coupled to a set of coil windings separate but included with the windings coupled to the AC power supply. The secondary power supply may be shared and common with a secondary powered supply for the flow generator circuit. In addition, a voltage regulator 184 provides power for the controller IC with the secondary power supply is in use.
The energy stored in the circuit is dissipated primarily into the heating element 22. The resistance of the induction coil 34 and connection wires 38 dissipates a relatively small portion of the energy. The circuit may be configured to have greater than ninety percent (90%) efficiency in transferring energy to the heating element.

The amount of heat produced by the heating element 22 may be controlled by regulating the energy stored in the induction coil 34. For example, the amount of heat produced can be regulated by:

i. Varying the ON time of switch Q1 to control the energy stored in the induction coil during each cycle, and

ii. Varying the supply voltage level to the L-C circuit to control the energy stored in the induction coil during each cycle.

In addition, the control circuit may monitor the inductance level (L) to determine that the heating element is present. If the heating element is not present, e.g., if the tub is not on the platform, the inductance (L) will be outside of a predetermined range and sensed by the controller. The control circuit may not turn ON the switch 46, 160 if the inductance is outside the prescribed range. Accordingly, the induction coupling (L) can be used to monitor for the tub and heating element.
The induction heating technique uses a small number of parts and can be controlled using a low cost power supply zero voltage switching control IC. Such ICs include an error amplifier which can be used in the feedback control circuit to achieve a controlled water temperature or output humidity level depending on the type of sensor used (i.e. a temperature or humidity sensor).

FIGURE 6 is a schematic side view of an alternative arrangement of a water tub 60 on a platform base 62. A ferrite ring core 64 is mounted on the upper planar surface of the platform. A core winding 66 is arranged on an upper surface of the core. The core and winding are elevated with respect to the platform. A bottom surface of the tub rests on the platform. A circular recessed section 68 in the bottom surface of the tub receives the core and winding. The gap between the outer surfaces of the coil and core, and recessed section of the tub is small, e.g., less than two millimeters.

Laminated ferrous, e.g., steel, plates 70, e.g. in a disc shape, are mounted on the bottom surface of the tub adjacent the recessed section. The ferrous plates 70 may include a frusto-conical section around and below the disc plate section. A lower surface of the plate may be coated with plastic. The plate are induction heated by the coil and core. The plate heats water in the tub. The plate is elevated above a lower surface of the bottom of the tub to heat water from a middle portion of the water level in the tub. A temperature sensor 32 on the platform senses the temperature of the bottom of the tub.
and thereby senses the temperature of the water in the
tub.

[0083] FIGURE 7 is a schematic diagram showing in side view
a humidification system 80 having a laminated heating
element and diaphragm 82 for providing moisture to an air
passage 84 extending from an air source 86 to a user face
mask 88. The heating element and diaphragm include a
magnetic metal plate (s) laminated with a water/vapour
filter diaphragm. The laminated heating element and
diaphragm is mounted on an assembly of a coil 90 and
ferrite core 92. Current flowing through the coil and
core assembly induce eddy currents on the heating element
which heat the element and the water 94.

[0084] The heated water passes as water vapour through
pores in the diaphragm and enters the air passage 84.
The laminated heating element and diaphragm can withstand
fairly high vapour pressures, such as 20 cm/H₂O. The
diaphragm is a filter that passes vapour but not water.
The filter material may be a type of polypropylene, that
may be similar to Gore-Tex ®. The diaphragm filter may
comprise layers of different material. The diaphragm may
be sandwiched between the ferrous plates of the heating
element. The plates may have apertures to allow for
passage of the vapour to and from the diaphragm. Humidity
is regulated by maintaining a constant water/vapour
pressure on the diaphragm and controlling the level of
power applied to the induction heating element. The
pressure is maintained at a constant level by allowing
vapour to vent through the diaphragm and into the air
passage. In addition, a pressure relief valve (not shown)
may be included in a sidewall of the container 96 to avoid an overpressure condition in the container. In addition, a temperature sensor 105 in the air passage 84 and/or water container 96 detects the water/vapour temperature and a controller ensures that the vapour temperature remains below a threshold level for safety and comfort.

[0086] The water is held in the container 96 that rests slightly above the coil 90 and houses the laminated heating element and diaphragm. The upper surfaces of the core 92 form a lower part of the container that is below the laminated heating element and diaphragm. A sealing wall 98 extends between the upper surface of the laminated heating element and diaphragm to the air passage 84. The surfaces of the coil and core exposed to water may be coated with a plastic to prevent corrosion and leakage of water. Vapour passes through the porous laminated heating element and diaphragm. The metal plates in the heating element are coated, e.g., with a plastic material, to avoid corrosion in the water.

[0087] The volume of water in the container is relatively small. Water is continually supplied to the container 96 from a water supply, which may be a water bottle 100 configured in a bird feeder type arrangement. The water bottle discharges water into a sealed feeding bowel 102 that provides water to the container 96 through a conduit 104. Water 64 fills the container 96 and is generally in contact with the heating element and diaphragm 82. As the water in the container 96 is consumed the reduced water pressure in the container draws water from the bowel 102.
Water in the bowel is replenished from the bottle. The neck of the bottle is inserted, e.g., screwed, into the sealed bowl to maintain the seal in the bowel and avoid having the bowl at atmospheric air pressure.

The air pressure in the sealed bowel is equalized with the pressure in the air passage 84 by an air conduit 104. The bowel is exposed to pressures above ambient pressure due to the air pressures in CPAP devices. There are also fluctuations in the pressure in the air passage 84 due to a patient breathing in the system. The air tube 104 balance the pressure in the bowel with the pressure in the CPAP air passage and thereby prevents collapse of the water-source 100.

FIGURE 8 is a schematic diagram of a side view of another embodiment of a induction heating diaphragm humidification system 110. A micro-meter pump 112, e.g., pulse pump, provides a flow of water from a water reservoir 114 to a cylindrical water container 116 that surrounds an air passage 118. A pressure regulator valve 120 provides precise control of the amount of water delivered to the container 116 by the pump 112.

An induction heating coil 120 is encased in a low loss, soft magnetic shell 122. The coil fits over the water reservoir 114 which fits over a laminated heating element and diaphragm 124. The concentric assembly of the coil, reservoir and heating element/diaphragm may be encased in a low-loss soft magnetic shell 122 which includes chambers separating the coil from the water reservoir. The outer cylindrical surface of the heating
element /diaphragm 124 forms an inner wall of the reservoir.

[0091] The ferrous heating element causes vapour to form from the water in the reservoir. The vapour passes through the porous diaphragm (which passes vapour but not water) and the vapour enters the flow passage 118. The vapour is represented as water droplets in the passage shown in the figure, however, this is for illustrative purposes only as large water droplets are not desirable.

[0092] Humidity is regulated by maintaining a constant pump power level and controlling the volume of water delivered for humidification. As water is converted to vapour, water pressure in the container 116 is reduced. The pressure regulator valve 120 allows additional water to replenish the container. If the container has sufficient water (as evident from an adequate water pressure level), the pressure regulator valve returns water from the pump 112 to the water container 114. A temperature sensor in the air passage and/or water container 116.

[0093] As shown in Figures 7 and 8, the humidifier may be located adjacent an air delivery conduit so that the air is humidified as it passes through the heating system. The humidifying system may be arranged, for example, along a lower wall of the air conduit (as shown in Fig. 7) or may form a sleeve around the conduit (as shown in Fig. 8). By reducing the volume of water in contact with the heating element (as is done in the embodiments shown in Figures 7 and 8), the water and heating element can be arranged in close proximity to the air passage and the
heating rate of the water can be relatively fast (as compared to heating a large volume of water). In these two embodiments, the water reservoir, e.g., water bottle 100 and reservoir 114, is separated from a relatively-small volume of water 106, 116, that is heated and is adjacent the fluid passage. The reservoir provides water automatically and as needed to the water container proximate to the air passage. The supply of water from the reservoir may be triggered by a decrease in pressure in the container that causes water to be drawn from the bowel to the container.

[0094] FIGURE 9 is a schematic diagram of a CPAP system 130 having an air passage 132, an air blower or fan 134 and humidifier 136. Humid, pressurized air flows through the passage 138 to a mask 139 on the face of a user.

[0095] The CPAP control system (see 48 in Fig. 2) may include a temperature sensor 140 to measure the temperature of the humid air flowing to the mask, and a temperature and/or humidity sensor 142 to measure ambient humidity and/or temperature of the atmospheric air drawn into the CPAP system. A flow meter (not shown) associated with the flow generator 130 determines the air flow through the passage 132. Knowing the ambient temperature and/or humidity, the temperature of the pressurized air flowing from the humidifier 136 and the length and air flow through the tube, the control system can determine the temperature of the pressurized air delivered to the user's mask.
FIGURE 10 is a chart showing a relationship between air tube length (represented in meters M) and air temperature (T) in the air tube. As indicated in the chart, air in the tube 138 decreases in temperature as it flows along the length of the tube. The longer the length of the tube, the greater is the drop in temperature when the air reaches the mask. The temperature decrease through the tube is also dependant on the volume of air flow through the tube. At high flow rates, the rate of temperature drop through the tube is less than for low flow rates.

The humidifier control algorithm applies the relationship (such as shown in Figure 10) between air temperature, tube length and average air flow to determine the drop in temperature as the air flows from the temperature sensor 140 at the output of the CPAP system 130 to the mask. In addition, the control algorithm may determine the mass of water evaporated into the air as a function of power (water vaporizes at 2.256 kj/g) applied to the heating element; ambient temperature of the air draw into the CPAP system and the air flow through the passage 138. The control system may adjust the power applied to the heating element (and other parameters of the CPAP system) to achieve a desired relative humidity (RH).

Further advantages of the induction heating technique disclosed include (without limitation) : (i) efficient heating which reduces input power requirements; (ii) minimal components for heating which results in lower manufacturing costs, (iii) fewer thermal impedances
which reduces variations between humidifier units, (iv) compatibility with low, voltage DC power and rectified high voltage AC power sources, (v) sealing the bottom of the humidifier tub, which may include the heating element, with plastic to ease cleaning, reduce corrosion, and prevent water leaks, (vi) where the heating element is embedded in the humidifier tub and coated with plastic, there are no exposed hot surfaces when the tub is removed either on the tub or on the humidifier chassis, (vii) the resonant frequency of the circuit changes if the metal heating disc are not present and thus the frequency (or voltage levels during the cycle) can be monitored to detect if the tub is present prior to the application of energy (if the tub is not present the controller does not apply current to the inductance coil), (viii) precise humidity control, and (ix) less variation in humidity control from unit to unit.

[0099] While the invention has been described in connection with what one presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the invention.
WHAT IS CLAIMED IS:

1. A humidifier comprising:

   a container to receive water;

   a heating element formed of a ferrous material;

   a heating unit including an induction coil and an control circuit, wherein the control circuit applies an alternating current (A-C) current to the coil if an inductance of the coil and heating element is within a predetermined range, and

   a gap separating the heating element from the induction coil, wherein the heating element is heated by an electromagnetic coupling with the induction coil.

2. The humidifier of claim 1 wherein the heating unit includes a ferrite core supporting the induction coil.

3. The humidifier of any one of claims 1 to 2 wherein the heating unit includes a resonance circuit comprising a capacitor in parallel with the induction coil and a switch operated by the control circuit, wherein the switch cyclically applies a power source to the resonance circuit.

4. The humidifier of any one of claims 1 to 3 wherein the heating element is a metallic plate with at least one surface in direct contact with water in the container.
5. The humidifier of any one of claims 1 to 4 wherein the heating element includes heat transfer fins extending into the water in the container.

6. The humidifier of any one of claims 1 to 5 wherein the heating element includes a raised underside surface exposed to water in the container.

7. The humidifier of any one of claims 1 to 6 wherein the heating element includes a recess on an underside surface wherein the recess is between an annular ring and a center disc on a lower surface of the heating element and wherein the ring and disc are mounted on a bottom surface of the container.

8. The humidifier of any one of claims 1 to 7 wherein the induction coil is raised such that it extends into a recess in a bottom of the container.

9. The humidifier of any one of claims 1 to 8 wherein the container is releasably supported by a platform and further comprising a ferrite core extending upward from the platform into a recess in a bottom of the container, wherein the induction coil is mounted on an upper portion of the core and the heating element is on an elevated portion of a bottom of the container and is adjacent the core.

10. The humidifier of any one claims 1 to 9 wherein the container is supplied with water from a separate water supply, wherein the water supply automatically maintains a constant supply of water in the container.
11. The humidifier of any one of claims 1 to 10 wherein the control circuit sensed the inductance of the coil and heating element, determines whether the sensed inductance is within a predetermined range and applies no current to the coil if the inductance is outside of the range.

12. The humidifier of any one of claims 1 to 11 wherein the container includes a non-conductive coating over at least a bottom surface of the container.

13. The humidifier of any one of claims 1 to 12 wherein the induction coil induces a current in the heating element, and the heating element warms as the current is dissipated by the heating element.

14. The humidifier of claim 13 wherein the current is an eddy current.

15. The humidifier of any one of claims 1 to 14 wherein the container includes an input connectable to a source of above-atmospheric air and an output for providing moisture carrying air connectable to a conduit leading to a breathing passage of a patient.

16. A Continuous Positive Airway Pressure (CPAP) or ventilator device comprising:

   a flow generator having an output of above-atmospheric air flow;
an air passage directing the air flow to a conduit, wherein the conduit leads to a user interface to supply air flow to the user; 

a water container adjacent the passage to provide moisture to the above-atmospheric air flow in the air passage; 

a magnetic heating element in the container and including at least one surface adapted to be exposed to water in the container; 

a platform including a support surface for the water container and housing a heating unit adjacent the support surface; 

said heating unit including an induction coil and an control circuit, wherein the heating element in the water container is separated by a gap from the induction coil wherein the heating element is heated by an electromagnetic coupling with the induction coil. 

17. The device of claim 16 wherein the heating unit includes a ferrite core supporting the induction coil. 

18. The device of any one of claims 16 to 17 wherein the heating unit includes a resonant circuit comprising a capacitor in parallel with the induction coil and a switch operated by the control circuit, wherein the switch cyclically applies a power source to the resonant circuit.
19. The CPAP device of any one of claims 16 to 18 wherein the heating element is a ferrous plate with at least one surface in direct contact with water in the container.

20. The CPAP device of any one of claims 16 to 19 the heating element includes heat transfer fins extending into the water in the container.

21. The CPAP device of any one of claims 16 to 20 wherein the induction coil induces a current in the heating element and the heating element warms as heat is generated by the current flowing through the heating element resistance.

22. The CPAP device of any one of claims 16 to 21 wherein the heating unit includes a ferrite core supporting the induction coil.

23. The CPAP device of any one of claims 16 to 22 wherein the heating unit includes a resonant circuit comprising a capacitor in parallel with the induction coil and a switch operated by the control circuit, wherein the switch cyclically applies a power source to the resonant circuit.

24. The CPAP device of any one of claims 16 to 23 wherein the heating element is a metallic plate with at least one surface in direct contact with water in the container.
25. The CPAP device of any one of claims 16 to 24 wherein the heating element includes heat transfer fins extending into the water in the container.

26. The CPAP device of any one of claims 16 to 25 wherein the heating element includes a raised underside surface exposed to water in the container.

27. The CPAP device of any one of claims 16 to 26 wherein the heating element includes a recess on an underside surface wherein the recess is between an annular ring and a center disc on a lower surface of the heating element and wherein the ring and disc are mounted on a bottom surface of the container.

28. The CPAP device of any one of claims 16 to 27 wherein the induction coil is raised such that it extends into a recess in a bottom of the container.

29. The CPAP device of any one of claims 16 to 28 wherein the container is releasably supported by a platform and further comprising a ferrite core extending upward from the platform into a recess in a bottom of the container, wherein the induction coil is mounted on an upper portion of the core and the heating element is on an elevated portion of a bottom of the container and is adjacent the core.

30. The CPAP device of any one claims 16 to 29 wherein the container is supplied with water from a separate water supply, wherein the water supply
automatically maintains a constant supply of water in the container.

31. The CPAP device of any one of claims 16 to 30 wherein the control circuit sensed the inductance of the coil and heating element, determines whether the sensed inductance is within a predetermined range and applies no current to the coil if the inductance is outside of the range.

32. The CPAP device of any one of claims 16 to 31 wherein the container includes a non-conductive coating over at least a bottom surface of the container.

33. The CPAP device of any one of claims 16 to 32 wherein the induction coil induces a current in the heating element, and the heating element warms as the current is dissipated by the heating element.

34. The CPAP device of claim 33 wherein the current is an eddy current.

35. The humidifier of any one of claims 16 to 34 wherein the container includes an input connectable to a source of above-atmospheric air and an output for providing moisture carrying air connectable to a conduit leading to a breathing passage of a patient.

36. A method for increasing humidity in a source of air being supplied to a breathing passage of a patient comprising:
conveying the air to a water container such that the air absorbs moisture;

outputting the moisture carrying air to a patient;

heating the water in the container with a heating element, and

inducing a current in the heating element by applying a changing electromagnetic field generated an induction coil, wherein the coil is separated by a gap from the heating element.

37. The method of claim 36 wherein the changing electromagnetic field is generated by applying an alternating current to the induction coil and said method further comprises:

cyclically applying a voltage source to the induction coil,

charging a resonant capacitor while the voltage source is applied to the induction coil, wherein the capacitor is in parallel to the coil, and

discharging the capacitor to the coil while the voltage source is turned off and not applied to the induction coil.

38. The method of claim 37 wherein a period during which the voltage is applied to the induction coil corresponds to a period required to charge the capacitor voltage and inductor current to a predetermined level,
and a period during which the capacitor and inductor exchange energy at a resonant frequency which leads to energy dissipation in the heater metal plate and corresponds to a period required to substantially discharge the stored energy.

39. The method of any one of claims 37 to 38 wherein the cyclical application of the voltage source includes transitions between applying the voltage source and discharging the capacitor and these transitions occur while substantially no voltage potential is applied across the switch.

40. The method of any one of claims 37 to 39 wherein the voltage source is an alternating current source.
Fig. 3
Fig. 5B
Fig. 9

Fig. 10

Tube Length

T

T ambien

T in

T cool

T out

High flow

Low flow

1M

2M
**INTERNATIONAL SEARCH REPORT**

**International application No.**
PCT/AU2007/000274

**A. CLASSIFICATION OF SUBJECT MATTER**

Int. Cl.

**A61M 16/16 (2006.01)**

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**DWPI +keywords:** humidify, induction and similar terms

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tbody>
<tr>
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□ Further documents are listed in the continuation of Box C  X See patent family annex

• Special categories of cited documents:
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**Date of the actual completion of the international search**
20 March 2007

**Date of mailing of the international search report**
27 MAR 2007

Name and mailing address of the [SA/AU]
AUSTRALIAN PATENT OFFICE
PO BOX 200, WODEN ACT 2606, AUSTRALIA
E-mail address: pct@ipaaustralia.gov.au
Facsimile No. (02) 6285 3929

Authorized officer

Xavier Gisz

Telephone No : (02) 6283 2064

Form PCT/ISA/2 10 (second sheet) (April 2005)
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<table>
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<td>US 5286942</td>
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Due to data integration issues this family listing may not include 10-digit Australian applications filed since May 2001.

END OF ANNEX