Abstract:

Liquid heating apparatus is provided for use with a water heating geyser having an opening therein. The liquid heating apparatus includes a heating element supported by a mounting plate, for transferring heat to liquid in the vessel, and at least one ultrasonic transducer supported by the mounting plate adjacent to the heating element and arranged to excite liquid in the vessel during operation of the heating element. Preferably a pair of ultrasonic transducers are arranged adjacent the heating element. A sonotrode may be coupled in use to an ultrasonic transducer, and is arranged to enhance circulation of heated liquid in an upper portion of the geyser. An ultrasonic drive circuit mounted on the apparatus drives the transducers to create streaming and cavitation, to enhance heating of water in the geyser.
LIQUID HEATING WITH ULTRASONIC EXCITATION

BACKGROUND OF THE INVENTION

THIS invention relates to a method of heating a liquid and to liquid heating apparatus.

During this time of global warming, carbon emissions taxation and spiralling electricity costs, it has become critical to find ways of saving electricity. The hot water cylinder (geyser) in a household is usually the single greatest consumer of energy. A geyser can contribute up to 50% of the total household electrical bill.

Conventional resistive heating elements are considered to be the most efficient way of heating water. Desirably, the water should be raised as rapidly as possible to the temperature set on the geyser thermostat and the heating element then switched off. Such elements consume huge amounts of energy, however, and poorly designed geysers do not use the resultant hot water in the most efficient manner. Conventional geysers use inducted heat to warm the water. The time required to heat the contents of the geyser is relatively long, and the way in which water behaves in a geyser when heated can be complex, creating thermal dines and mixing problems.

It is an object of the invention to provide an alternative water heating method and apparatus.
SUMMARY OF THE INVENTION

According to the invention there is provided liquid heating apparatus for use with a vessel for liquid having an opening therein, the liquid heating apparatus including:

- a heating element supported by a mounting plate for transferring heat to liquid in the vessel; and

- at least one ultrasonic transducer supported by the mounting plate adjacent to the heating element and arranged to excite liquid in the vessel during operation of the heating element.

The vessel for liquid may be a water heating geyser.

The heating element may be a resistive electrical heating element which is immersed in liquid in the vessel in use.

In one embodiment, the apparatus includes first and second ultrasonic transducers supported by the mounting plate adjacent to the heating element.

The apparatus may include a sonotrode coupled in use to said at least one ultrasonic transducer, wherein at least one of the location, orientation, size and configuration of the sonotrode are selected to enhance circulation of heated liquid in an upper portion of the vessel.

In the case of a water heating geyser, the location of the heating element and the ultrasonic transducer with its associated sonotrode may be selected to cause more rapid heating of water in an upper region of the geyser than in a lower region thereof.

For example, the sonotrode may comprise a metallic rod which protrudes into the interior of the vessel, extending substantially parallel to the resistive heating element.
The apparatus preferably includes an ultrasonic generator supported on or adjacent the mounting plate and arranged to drive said at least one ultrasonic transducer.

The ultrasonic generator preferably includes a controllable drive circuit for applying an ultrasonic drive signal to said at least one ultrasonic transducer, and a control circuit arranged to receive a feedback signal from said at least one ultrasonic transducer and to vary at least one characteristic of a control signal applied to the drive circuit to maintain the frequency and power of the ultrasonic drive signal within predetermined parameters.

In one embodiment, the ultrasonic generator is arranged to drive said at least one ultrasonic transducer within a bandwidth having upper and lower limits that are higher and lower, respectively, than a centre frequency based on a resonant frequency of said at least one ultrasonic transducer.

The ultrasonic generator and the resistive electrical heating element are preferably connected to a common electrical input of the apparatus, so that the apparatus can be used to replace a conventional heating element of a water heating geyser.

Said at least one ultrasonic transducer may have an operating frequency in the range 20 kHz to 80 kHz.

The invention extends to a water heating geyser including liquid heating apparatus as defined above.
BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram showing the general layout of an example embodiment of water heating apparatus according to the invention;

Figure 2 is a schematic diagram illustrating major components of the water heating apparatus and equivalent electromechanical and electrical circuit representations of the components;

Figure 3 is a diagram illustrating liquid circulation in a vessel due to ultrasonic excitation thereof;

Figure 4 is a schematic circuit diagram of a control circuit for an ultrasonic transducer of the example apparatus;

Figure 5 is a schematic diagram of a transducer driver circuit controlled by the circuit of Figure 4 in the example apparatus;

Figure 6 is a plot showing the performance of a conventional 1kW water heater using only a resistive heating element;

Figure 7 is a plot similar to that of Figure 6 showing the performance of the same water heater with ultrasonic excitation of the liquid being heated;

Figure 8 is a partial sectional side view of a second example embodiment of water heating apparatus according to the invention;

Figure 9 is a plan view of the apparatus of Figure 8; and

Figure 10 is a simplified schematic diagram of an ultrasonic drive circuit used in conjunction with the apparatus of Figures 8 and 9.
DESCRIPTION OF EMBODIMENTS

A first embodiment of water heating apparatus according to the invention is shown in Figure 1. The drawing shows a hot water cylinder or geyser 10 which is generally conventional in construction. The geyser has a casing 12 which is liquid impervious and insulating. Such geysers are well known to those skilled in the art and the casing is therefore not described in greater detail herein.

As indicated in Figure 1, the geyser is orientated generally horizontally. At one end of the casing 12 is a flattened end surface 14 on which is mounted a plate with an aperture formed therein for receiving a conventional resistive heating element 16. Additionally, a second aperture is provided adjacent to the first, through which a metallic rod 18, preferably a stainless steel rod, protrudes into the interior of the casing, extending parallel to the resistive heating element 16. The stainless steel rod 18 conveniently fits into a tubular pocket which is conventionally provided for a thermostat in a conventional geyser arrangement. The conventional thermostat is not required in the described apparatus.

The rod 18 is connected to an ultrasonic transducer 20, which is driven by a control circuit and an associated driver circuit 22. The ultrasonic transducer 20 can also be fitted directly to the flattened end surface 14, such that the pressure wave is transmitted through the flattened end surface 14; or the flattened end surface 14 can be modified so that the face of the ultrasonic transducer 20 comes into direct contact with the water inside the vessel and the ultrasonic transducer 20 is suitably sealed to contain the pressure inside the vessel. A temperature sensor 24 is connected to a hot water outlet pipe 26 which exits the uppermost side of the casing and provides a temperature feedback signal to the circuit 22.

It can be seen from Figure 1 that the resistive heating element 16 and the stainless steel rod 18 are located approximately one third of the vertical
distance A from the lower side of the geyser, at the lower edge of a central region B and well below an upper region C.

The stainless steel rod 18 acts as a sonotrode which couples the ultrasonic energy of the transducer 20 to the liquid in the casing 12. The location, size and shape of the sonotrode, together with the frequency, amplitude and modulation of the ultrasonic waveform applied to the sonotrode, determine the cavitation and circulation effects of the ultrasonic energy introduced into the liquid in the casing.

In operation the resistive heating element 16 is operated conventionally to heat liquid in the geyser casing 12. At the same time, the ultrasonic transducer is operated according to a predetermined scheme to excite the liquid, causing cavitation in the liquid and resultant streaming or circulation of the liquid in the casing. The location, orientation, size and configuration of the sonotrode 18 are selected to enhance circulation of the heated liquid in the upper third of the vessel (region C), reducing the time required to heat a useful amount of liquid in the geyser. The temperature sensor 24 provides a feedback signal related to the temperature of the liquid in this region of the geyser to the circuit 22.

The operation of the apparatus is discussed in more detail below.

The operation of the ultrasonic transducer and its associated sonotrode are designed to generate longitudinal pressure waves within the liquid to be heated.

Longitudinal pressure wave generation involves the use of high-frequency sound waves (generally above the upper range of human hearing, or about 18 kHz). Between 20 and about 100 kHz, waves are defined as "low frequency ultrasound" or "power ultrasound". Energy is transferred at a high power level and is able to modify the medium in which it propagates (in this example, water). Power ultrasound can disrupt a fluid bulk to create cavitation and/or
acoustic streaming, two phenomena with powerful macroscopic effects for heat transfer enhancement.

Acoustic streaming ensues from the dissipation of acoustic energy which permits the gradients in momentum, and thereby the fluid currents. The speed gained by the fluid allows a better convection heat transfer coefficient near the solid boundaries, sometimes leading to turbulence and promoting heat transfer rate.

Acoustic cavitation is the major effect of ultrasonic heat transfer enhancement. Indeed, a bubble implosion near a solid-liquid interface disrupts thermal and velocity boundary layers, reducing thermal resistance and creating microturbulence.

In cavitation, micron-size bubbles form and grow due to alternating positive and negative pressure waves in a liquid. The bubbles subjected to these alternating pressure waves continue to grow until they reach resonant size and implode. Just prior to the bubble implosion there is a tremendous amount of energy stored inside the bubble itself.

The pressure inside a cavitating bubble can be extremely high, with pressures up to 500 atm. (1atm = 1,01325bar.) The implosion event, when it occurs near a hard surface, changes the bubble into a jet about one-tenth the bubble size, which travels at speeds of up to 400 km/h toward the hard surface.

In order to produce the required positive and negative pressure waves in the liquid to be heated, a mechanical vibrating device comprising a diaphragm/sonotrode attached to an ultrasonic transducer is used. The transducer, which vibrates at its resonant frequency due to energisation by a high-frequency electronic generator source, induces amplified vibration of the diaphragm/sonotrode. This amplified vibration is the source of positive and negative pressure waves that propagate through the liquid in the vessel. When transmitted through water, these pressure waves cause the cavitation processes.
The resonant frequency of the transducer determines the size and magnitude of the resonant bubbles. Typically, ultrasonic transducers having an operating frequency from 20kHz to 80 kHz or even somewhat higher are used. Lower frequencies tend to create larger bubbles with more energy.

The basic components of the longitudinal pressure wave system include an ultrasonic transducer coupled to a radiating diaphragm or sonotrode. A control circuit including an electrical generator is provided to drive the transducer, and a digital temperature sensor or thermostat is provided to permit temperature control. A key component is the transducer that generates the high-frequency mechanical energy. There are two types of ultrasonic transducers used in the industry, piezoelectric and magnetostrictive. Both have the same functional objective, but the two types have dramatically different performance characteristics.

Piezoelectric transducers are made up of several components. A ceramic (usually lead zirconate) crystal is sandwiched between two strips of tin. When a voltage is applied across the strips it creates a displacement in the crystal, known as the piezoelectric effect. When these transducers are mounted to a diaphragm or sonotrode coupled to the liquid in a vessel, the displacement in the crystal causes a movement of the diaphragm or sonotrode, which in turn causes a pressure wave to be transmitted through the liquid in the vessel. In the present example, the sonotrode is a stainless steel rod. Because the mass of the crystal is not well matched to the mass of the stainless steel sonotrode, an intermediate aluminium block is used to improve impedance matching for more efficient transmission of vibratory energy from the transducer to the sonotrode. The assembly is relatively inexpensive to manufacture. This low cost makes piezoelectric technology preferable for the longitudinal pressure wave assisted heating of the present invention.

The longitudinal pressure wave generator converts a standard electrical frequency of 50/60 Hz at 110/220V RMS into the higher or lower frequencies
required, generally in the range of 20 kHz to 80 kHz in the high range, or below 20 kHz in the low range.

Preferably, the transducer control and driver circuits use frequency sweep techniques to drive the transducers within a bandwidth having upper and lower limits that are slightly higher and slightly lower, respectively, than a centre frequency based on the transducer resonant frequency. For example, a transducer designed to operate at 30 kHz may be driven by a generator that sweeps between 29 and 31 kHz. This technique eliminates standing waves and hot spots in the vessel that would result from the use of fixed-frequency generators. The necessary control signals can be obtained by using an analogue sweep frequency generator or a digital waveform generator, and autofollow circuitry. Autofollow circuitry is designed to maintain the centre frequency when the liquid heating vessel is subjected to varying load conditions. With autofollow circuitry, the generator operates to match the electrical load with the mechanical load, providing optimum output at all times to the liquid inside the vessel.

To test the operation of a prototype system, a longitudinal pressure wave transducer producing a zone of cavitation was submerged into a tank filled with water (see Figure 2). The kinematic viscosity of water is good, having appropriate Reynolds-numbers for laminar flow. Flow turbulence creates a jet stream due to cavitation and velocity impact of the pressure wave due to the ultrasound transducer. To visualize the flow (streaming lines) ink was injected into the tank with the transducer at the side. This made the mixing profile of water in the tank visible as shown in Figure 3. It can be seen that the effect of the ultrasonic transducer is to circulate the liquid around the tank.

In order to investigate the operation of the invention in terms of flow and mixing phenomena, some parameters are introduced:

*Treatment time:* The time it takes to treat 99% of the volume in the vessel.
Mixing: The exchange of mass between the heated volume and unheated volume. If a volume of liquid passes through the cavitation zone, it is considered to be 100% treated, if then, this volume becomes "diluted" by the liquid from the untreated volume, it can be considered mixed or partially treated. This mixing is caused by turbulence, not by diffusion.

Minimal treatment time ($t_{\text{minimal.treatment}}$): The time it takes to treat the entire volume of the liquid in the vessel when no mixing occurs. Each unit volume is considered untreated unless it has passed the cavitation zone. If $Q$ is the flow rate through the cavitation zone and $V$ the total volume of the liquid, $t_{\text{minimal.treatment}} = \frac{V}{Q}$.

Circulation time ($t_{\text{circulation}}$): The minimum time required to reach the situation when each unit volume entering the cavitation zone is not 0% treated.

Dead zones: Zones with no interaction with the rest of the liquid, except by diffusion. These lead to very long treatment times.

Jet speed: The maximum flow velocity in the jet stream under the cavitation pressure wave transducer.

The ultrasonic transducer is controlled by a control circuit, shown schematically in Figure 4. The circuit is controlled by a microprocessor. PWM control pulses are derived from the LTC6990 oscillator circuit under microprocessor control. The drive waveform duty cycle and frequency are controlled by this circuit. The output of the control circuit operates a power driver stage for the ultrasonic transducer.

The power driver stage is shown in Figure 5. This circuit has a stabilised and rectified voltage-doubled DC supply operating at between 300 to 600V. The exciting waveform is applied to the transducer by power FETs via transformers to obtain the necessary operating voltages. The supply voltage translates to cavitation "force" in the application.
Referring again to the test equipment shown in Figures 2 and 3, the flow of water in the tank due to pressure wave agitation can be characterised by a differential equation (1) which takes into account the fraction of untreated liquid. Some assumptions made for the equation’s validity are as follows:

1. The moment the water flows through the cavitation zone in contact with the transducer sonotrode it is considered 100% treated.
2. Minimal or no dead zones (areas where no effect is felt) are present.
3. On average, all liquid follows a sequential path, i.e. liquid leaving a zone first will return to the zone first.
4. The flow is fully developed.

\[-\frac{Q}{V} p(t-t_{\text{circulation}}) = \frac{dp}{dt}, \quad p(t-t_{\text{circulation}} \leq 0) = 1\]

\(Q = \text{flow rate through the cavitation zone}\)
\(V = \text{total volume}\)
\(p = \text{fraction of untreated liquid}\)
\(t_{\text{circulation}} = \text{circulation time}\)

5. Eddies would be present in the upper and lower half of the volume if both are symmetrical.
6. There is a 'slow' zone in the upper and lower corners due to symmetry.
7. All flow is turbulent.

The estimated jet stream speed seems independent of volume and could vary between 0.7 - 1.3 m/s as indicated in Figure 3. The computational fluid dynamics give, based on the jet speed, an average flow rate Q that is also independent of total volume in the tank.

The effect of the cavitation and streaming phenomena described above is that liquid in the top third of the geyser volume is heated to the required operating temperature relatively quickly, by assisting heated liquid in the vicinity of the
element to be propelled by turbulence/ agitation to reach this "active region" of the hot water geyser quickly.

The cavitation region surrounding the sonotrode and the effect of extremely high pressure, high velocity micro-implosions with associated shock waves appears to alter the microscale physics of the liquid in a vessel, with otherwise normal radiative and convective heat transfer at a known pressure.

The performance of a conventional geyser is shown in the plot of Figure 6, indicating an initial heating time to 65 degrees C was 6655 seconds, using a 1 kW electric heating element. The effect of cavitation and longitudinal pressure wave assisted heat transfer is indicated in the plot of Figure 7. Here, the mere addition of 70W of ultrasonic pressure waves at 36kHz caused the target heating temperature of 65 degrees centigrade at the top and bottom of the tank to be reached at 47 percent faster. This test was independent of the jetstream effect which has to be added. There is indicated in the apparatus of the invention the rapid heating of the top one-third of the tank aided by ultrasonic cavitation. The jetstream effect also increases the ability of the hot water to mix quicker and as the temperature at the top of the geyser is controlled, an added saving in time to heat is obtained.

The heating time in the ultrasonically assisted geyser was 3147 seconds as read from the Labview data acquisition card attached to a monitoring control laptop used in the experiment. As can be observed from Figure 7, both upper and lower geyser zone temperatures attained remarkable uniformity with the use of cavitation in the water.

These tests were performed in open tank systems under normal atmospheric pressure. One can therefore conclude that under 400 kPa pressure, as in a pressurised geyser, the effect would be even more pronounced. It is estimated that a minimum savings on electricity consumption for water heating of 30 % is possible using the technology of the invention.
To give an example, a typical 3kW geyser heater element, cycled at 50% and on for 8 hours a day, heating a differential temperature of 5 degrees C per day, averaged over a period of a year, would consume $3 \times 5 \times 8 = 120\text{kWh}$ per day. Multiplied by 365 days, this gives us 43000kWh. With the cost of electricity at R1.10 per kWh, this gives us R47 300.00 per annum or R129.00 per day.

With the present invention, this cost could be reduced by about 50%, which means that in conjunction with energy savings technology such as solar geysers, a cost saving of up to 90% should be possible.

Initial tests indicate that the use of ultrasonic excitation of water in an otherwise conventional geyser, thereby producing cavitation and longitudinal pressure wave assisted heating, results in an improvement in the time taken to achieve a target water temperature of typically 30% or better. The ultrasonic transducer and related circuitry has a negligible energy consumption compared to the heater itself. The overall energy consumption of the geyser is expected to be substantially reduced.

The ultrasonic transducer with its associated sonotrode or transmission rod fits into the standard pocket that is provided for the thermostat in a conventional geyser, thus simplifying the installation process and permitting retrofitting without the need to drain the geyser. The control circuit, driver circuit and digital thermostat are preferably manufactured as a one-piece unit with the transducer and sonotrode.

The effects of acoustic cavitation assist in dealing with the problem of geysers fouling up when operating in hard water areas. In such areas, solids tend to build up on the element and geyser wails causing premature failure of the element and/or geyser. The acoustic agitation due to the method of the invention loosens the solids and places them in suspension in the water, so that they can be flushed out of the geyser during the withdrawal of hot water.
It will be appreciated by those skilled in the art that although the present invention has been described with reference to the heating of water in domestic geysers, the invention is not limited to the heating of water but can be applied to the heating of other liquids. Similarly, the apparatus used to heat the liquid need not be a geyser or use a resistive heating element, but could be a vessel of substantially different shape and characteristics, and the heating element used could be one of many different types.

A second embodiment of the invention is shown in Figures 8 and 9. This embodiment is designed as a replacement water heating unit which can replace a conventional resistive heating element in a domestic water heating geyser.

In this embodiment, a circular mounting plate or flange plate 28 is provided which supports both a conventional resistive element (not shown for clarity) and a pair of ultrasonic transducers 30 and 32. The plate 28 also supports a thermostat 34 and an ultrasonic drive circuit or amplifier 36. The unit has a housing 38 which encloses the transducers and thermostat and on the ultrasonic drive circuit is mounted on the rear thereof.

A single pair of electrical conductors 40 enable connection of the unit to the AC mains supply, and feed the thermostat/resistive element as well as the ultrasonic drive circuit. Thus, the unit is configured as a drop-in replacement for a conventional geyser element unit and does not require additional electrical connections or particular expertise on the part of installation personnel.

Figure 10 shows the arrangement of the ultrasonic drive circuit or amplifier 36 in more detail. The circuit includes an AC line interface 42 which includes a noise filter, a fuse and inrush current protection. An auxiliary DC supply 44 is fed from the filtered AC. The main output of the line interface is fed to a power factor correction circuit 46 and from there to a voltage control circuit 48 which is responsive to PWM voltage control signals from a control circuit 50. The voltage-controlled output of the circuit 48 is fed to a full bridge drive circuit 52
which is also controlled by PWM drive signals from the control circuit 50. The output of the drive circuit 32 is fed through an impedance matching circuit 54 to the pair of ultrasonic transducers 30 and 32.

The described circuit provides frequency tracking stabilisation as well as current to voltage tracking (phase correction) so that the required power is always within predetermined limits and in phase. Therefore the required parameters of power and frequency are met independent of the influence of the ambient temperature or geyser temperature upon the drive circuit and the transducers.

The system can use dual or single transducers. In the prototype apparatus a pair of 50W 28kHz transducers were used instead of a single 100W 28kHz transducer. Using two smaller transducers side by side provides space to fit the standard thermostat, retaining the safety features of the conventional resistive heating unit. It is proposed to use a pair of 60W 80kHz transducers in order to move the operating frequency of the system above the hearing range of animals.
CLAIMS

1. Liquid heating apparatus for use with a vessel for liquid having an opening therein, the liquid heating apparatus including:

   a heating element supported by a mounting plate for transferring heat to liquid in the vessel; and

   at least one ultrasonic transducer supported by the mounting plate adjacent to the heating element and arranged to excite liquid in the vessel during operation of the heating element.

2. Liquid heating apparatus as claimed in claim 1 wherein the vessel for liquid is a water heating geyser.

3. Liquid heating apparatus as claimed in claim 2 wherein the heating element is a resistive electrical heating element which is immersed in liquid in the vessel in use.

4. Liquid heating apparatus as claimed in claim 2 or claim 3 including first and second ultrasonic transducers supported by the mounting plate adjacent to the heating element.

5. Liquid heating apparatus as claimed in claim 3 or claim 4 including a sonotrode coupled in use to said at least one ultrasonic transducer, wherein at least one of the location, orientation, size and configuration of the sonotrode are selected to enhance circulation of heated liquid in an upper portion of the vessel.

6. Liquid heating apparatus as claimed in claim 5 wherein the sonotrode comprises a metallic rod which protrudes into the interior of the vessel, extending substantially parallel to the resistive heating element.
7. Liquid heating apparatus as claimed in any one of claims 1 to 6 including an ultrasonic generator supported on or adjacent the mounting plate and arranged to drive said at least one ultrasonic transducer.

8. Liquid heating apparatus as claimed in claim 7 wherein the ultrasonic generator includes a controllable drive circuit for applying an ultrasonic drive signal to said at least one ultrasonic transducer, and a control circuit arranged to receive a feedback signal from said at least one ultrasonic transducer and to vary at least one characteristic of a control signal applied to the drive circuit to maintain the frequency and power of the ultrasonic drive signal within predetermined parameters.

9. Liquid heating apparatus as claimed in claim 8 wherein the ultrasonic generator is arranged to drive said at least one ultrasonic transducer within a bandwidth having upper and lower limits that are higher and lower, respectively, than a centre frequency based on a resonant frequency of said at least one ultrasonic transducer.

10. Liquid heating apparatus as claimed in any one of claims 7 to 9 wherein the ultrasonic generator and the resistive electrical heating element are connected to a common electrical input of the apparatus, so that the apparatus can be used to replace a conventional heating element of a water heating geyser.

11. Liquid heating apparatus as claimed in any one of claims 1 to 10 wherein said at least one ultrasonic transducer has an operating frequency in the range 20 kHz to 80 kHz.

12. A water heating geyser including liquid heating apparatus as claimed in any one of claims 1 to 11.
Fig. 2
Tank

Fig. 3
Jetstream
Mixing of
liquid in tank

SUBSTITUTE SHEET (RULE 26)
\[ f_{out} = \frac{1 \text{MHz} \cdot 50 \text{k} \Omega}{R_{VCO}} \cdot \left( \frac{R_{VCO}}{1 + R_{SET}} \right) \frac{D_{IN}}{D_{IN} + 4096} \]

\[ D_{IN} = 0 \text{ to } 4095 \]

**Fig. 4**

SUBSTITUTE SHEET (RULE 26)
INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2012/057743

A. CLASSIFICATION OF SUBJECT MATTER

F24H 1/00 (2006.01) F24H 9/00 (2006.01) H05B 3/82 (2006.01) B06B 1/02 (2006.01) B08B 3/12 (2006.01) F28F 13/10 (2006.01) F28G 7/00 (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)

EPOQUEENet search on cluster $MYDB$ (consisting of WPI and EPDOC): IPC and CPC (F24H1, F24H9, H05B3, B06B1/02, B08B3/12, F28G7/00, F28F13/10) with Keywords (GEYSER, WATER, FLUID, LIQUID, HEATER, IMMERSION, RESISTANCE, SONIC, VIBRATE, OSCILLATE, TRANSDUCER, SONOTRODE, SOUND 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>
</tr>
</thead>
</table>

Documents are listed in the continuation of Box C

Further documents are listed in the continuation of Box C

See patent family annex

* Special categories of cited documents:

“**” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“**” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“**” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“**” document member of the same patent family

Date of the actual completion of the international search
22 April 2013

Date of mailing of the international search report
22 April 2013

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE
PO BOX 200, WODEN ACT 2606, AUSTRALIA
Email address: pct@ipaustralia.gov.au
Facsimile No.: +61 2 6283 7999

Authorised officer

Rajeev Deshmukh
AUSTRALIAN PATENT OFFICE
(ISO 9001 Quality Certified Service)
Telephone No. 0399359622

Form PCT/ISA/210 (fifth sheet) (July 2009)
<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>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>TW 201043875 A1 (BEAUTY SILKS CO LTD) 16 December 2010 Abstract; figure 1; page 7, lines 21 to 25</td>
<td>1-12</td>
</tr>
<tr>
<td>A</td>
<td>GB 1467784 A (FIBRA-SONICS, INC.) 23 March 1977 Figures 1 and 2; page 3, line 127 to page 4, line 74</td>
<td>1-12</td>
</tr>
<tr>
<td>A</td>
<td>DE 10 2007 040 031 A1 (ROBIONEK, H.-J.) 26 February 2009 Figure 1; paragraphs [0026] to [0029]</td>
<td>1-12</td>
</tr>
<tr>
<td>X</td>
<td>DE 10 2005 054 159 A1 (FUCHS, P.) 16 May 2007 Figures 1, 3 and 4; paragraph [0024]</td>
<td>1-7, 10-12</td>
</tr>
<tr>
<td>A</td>
<td>Figures 1, 3 and 4; paragraph [0024]</td>
<td>8-9</td>
</tr>
<tr>
<td>A</td>
<td>DE 102 45 824 B3 (BSH BOSCH UND SIEMENS HAUSGERÄTE GMBH) 26 February 2004 Abstract; figure 1</td>
<td>1-12</td>
</tr>
<tr>
<td>A</td>
<td>CH 621 270 A5 (JEAN GALLAY S.A.) 30 January 1981 Figures 1 and 2; page 3, lines 34 to 42</td>
<td>1-12</td>
</tr>
</tbody>
</table>
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Publication Number</strong></td>
<td><strong>Publication Number</strong></td>
</tr>
<tr>
<td>TW 201043875 A1</td>
<td>None</td>
</tr>
<tr>
<td>US 2010/0154819 A1</td>
<td>None</td>
</tr>
<tr>
<td>GB 1 467 784 A</td>
<td>None</td>
</tr>
<tr>
<td>DE 10 2007 040 031 A1</td>
<td>None</td>
</tr>
<tr>
<td>DE 10 2005 054 159 A1</td>
<td>None</td>
</tr>
<tr>
<td>DE 102 45 824 B3</td>
<td>None</td>
</tr>
<tr>
<td>CH 621 270 A5</td>
<td>None</td>
</tr>
</tbody>
</table>

**Publication Date**
- TW 201043875 A1: 16 Dec 2010
- GB 1 467 784 A: 23 Mar 1977
- DE 102 45 824 B3: 26 Feb 2004
- CH 621 270 A5: 30 Jan 1981

**End of Annex**

Due to data inteception issues this family listing may not include 10 diol Australian applications filed since May 2001.

Form PCT/ISA/210 (Family Annex) (July 2009)