

Aeroponics Apparatus

The present invention relates to an aeroponics apparatus for use in an indoor farming system for the growing of plants, for example a vertical farm or greenhouse. In particular, the present invention utilises an ultrasonic nebulizer with an ultrasonic horn (or sonotrode) to impart
5 ultrasound waves to a nutrient solution in a reservoir of a grow bed in order to cause part of the nutrient solution to atomise and form a dense, nutrient rich, aerosol or mist to feed the root systems of the plants located directly above the grow bed. The term 'aeroponics' is to be understood to encompass growing systems in which the plant roots are allowed to grow into the nutrient solution, such that they can take up water directly from the nutrient solution (such
10 a system could be referred to as a hydro/aeroponic system).

It is known to use an ultrasonic nebulizer (or ultrasonic fogger) to create aerosols to provide water and nutrients to plant roots. However, prior art systems utilising ultrasonic nebulizers have characteristics which cause a number of problems for the operators of indoor farming systems in which they are utilised. It is desired to have an aeroponic apparatus which
15 maximises the working life of the equipment, for example the ultrasonic transducer or the grow bed, which can utilise the least amount of electrical energy to create the desired level of aerosol, which is easy to keep clean and which has a minimum level of complexity, in order to minimise the cost of both building or buying the equipment and maintaining it. This list of requirements is not easy to satisfy, and it is not met by the prior art aeroponics systems.

In some prior art systems, the ultrasonic nebulizers are fixed to the bottom of the reservoir of the grow bed, such that the ultrasonic transducer and, for a piezoelectric transducer, the piezoelectric disc, is in direct contact with the nutrient solution. This causes a problem when cleaning the apparatus because the cleaning has to take place around each nebulizer, for
20 example in the region where the nebulizer joins the grow bed. The area around each nebulizer provides a breeding ground for bacteria and thus poses a risk to the health of the plants within the grow bed. It is inevitable that an aeroponic system will create plant detritus and any such organic matter will build-up in the area around the nebulizers and the region where they adjoin the bed. This is undesirable because those build-ups will allow harmful bacteria to grow and the build-ups can become a breeding ground for insects and other pests. In the case of a
25 piezoelectric transducer it is disadvantageous to place the piezoceramic material in the nutrient solution because actuation of the piezoelectric transducer causes microfissures to form in the protective coating (resin) on top of the piezoceramic material and nutrient solution can then come into contact with that piezoceramic material. That contact with the nutrient solution causes stray current which can reduce the performance of the transducer or lead to
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its failure. However, there are good reasons why the prior art arrangements place the ultrasonic nebulizers within the reservoir and in contact with the nutrient solution.

Placement of the ultrasonic transducers in direct contact with the nutrient solution means that there is a very low level of attenuation of the ultrasound waves. Any interface between the ultrasonic transducers and the nutrient solution results in attenuation of the ultrasound waves as they travel from the ultrasonic transducer and through the nutrient solution. The efficiency of converting electrical energy into the generation of aerosol is thus maximised, through reduction of interfaces. This is beneficial because it reduces the operating cost of the farm. It is also noted that reflection of the ultrasound waves occurs when they pass through an interface and this reflection results in attenuation of the ultrasound waves, which is the cause of the majority of the reduction in the ultrasonic energy that is available for the generation of aerosol. The proportion of sound reflected at an interface is dependent upon the impedance of the materials. Reflection at an interface is reduced if the ultrasound waves are travelling from a high impedance material to a low impedance material for example, from plastic to metal to liquid.

In addition, in locating the ultrasonic nebulizers within the reservoir they can be readily fixed to the bottom of the reservoir, typically with a mechanical fixing such as a screwed or bolted fixture.

It is also the case that an ultrasonic transducer generates a great deal of heat when it is being operated. If the ultrasonic transducer is placed in the nutrient solution then the heat is dissipated by that nutrient solution. In the absence of such an efficient way of dissipating the heat then at best, the working life of the ultrasonic transducer will be reduced, and it is even possible for the ultrasonic transducer to burn out. In either scenario the farm owner will incur undesirable additional costs, alongside farm downtime resulting in loss in revenue. The heat dissipation potential of the nutrient solution also ensures that the ultrasonic transducer does not overheat. Additionally, the grow beds are typically made of a polymer material and heat from an un-cooled ultrasonic transducer can cause degradation of the polymer material, leading to a reduced working life of the grow bed. It can also cause the polymer material to melt, causing the grow bed to fail whereby it must be replaced immediately. However, it is not desirable to radiate excess heat into the nutrient solution because the temperature of the nutrient solution should be kept stable, measured relative to the aerial temperature, to maximise crop yield and maintain the health of the plants. Consequently, utilising the nutrient solution as a heat sink is sub-optimal.

There is no straightforward solution for overcoming these problems.

Placing a cover over the ultrasonic nebulizer, so that the ultrasonic transducer is no longer in contact with the nutrient solution, would mean that the working life of the transducer would no longer be reduced due to contact with the nutrient solution, but the cooling effect of the nutrient solution would be reduced and so the transducer may fail early due to running at a temperature that is too high. In addition, placing a cover over the ultrasonic nebulizer would lead to an attenuation of the ultrasound waves and a reflection of ultrasound waves at the interface of the cover, which would require that the ultrasonic transducer is driven at a higher voltage, with the result that the energy usage is higher (energy efficiency falls) and the life of the transducer is decreased.

Simply taking the piezoelectric transducer out of the nutrient reservoir and adhering it to the underside of the grow bed tray will not provide the solution to the problems either. If the piezoelectric transducer has been taken out of the heat sink, provided by the nutrient solution, then it will suffer from a reduced working life due to being operated at a temperature that is higher than the optimal temperature. Also, the grow bed will act to attenuate the ultrasound waves because of the inherent impedance properties of the grow bed material and because the interface will cause reflection of some of the ultrasound waves. Consequently, the ultrasonic transducer would need to be driven harder. A higher driving voltage and higher instantaneous current would be used. This has the disadvantage that repeated exposure of the piezoelectric transducer to such voltages and currents can damage the transducer, particularly when the voltages and currents are over a threshold. The result is that the energy usage is higher (energy efficiency falls) and the life of the transducer is decreased (as above). This may also result in overheating of the grow bed, leading to material degradation or failure.

According to the present invention there is provided an aeroponics apparatus comprising a grow bed with a reservoir for containing a liquid or a solution, an ultrasonic nebulizer module attached to the grow bed, the ultrasonic nebulizer comprising an ultrasonic horn having an input end connected to an ultrasonic transducer and an output tip wherein the ultrasonic horn is in contact with a wall of the reservoir. The ultrasonic horn can be configured so that its shape amplifies, i.e. increases the amplitude of, the ultrasound waves being produced by the ultrasonic transducer whilst remaining in resonance with the ultrasonic transducer. An ultrasonic horn which amplifies, i.e. which increases the amplitude of the ultrasound waves, increases the conversion efficiency of electrical to mechanical energy. This results in more energy being converted and less energy being wasted. The amplification / increase in amplitude is advantageous because it can be used to compensate for the reflection of the ultrasound waves when they pass across any interface that is located between the ultrasonic transducer and the liquid or solution within the reservoir and thus it ensures that the ultrasound

waves are able to generate the desired quantity of aerosol. The amplification is also advantageous because it enables the energy requirements of the ultrasonic transducer to be reduced. A lower 'driving' voltage can be utilised to generate the desired quantities of aerosol and this makes it cheaper to operate the farm. An amplifying ultrasonic horn allows the ultrasonic nebulizer to generate the same amount of aerosol but with a lower power consumption than would otherwise be the case, thus reducing the amount of electricity that is used. An increase in the conversion efficiency of electrical to mechanical energy means that energy is conserved in a high grade form. This is contrasted with a device for transmitting ultrasound waves from a transducer that would convert the energy in those waves into a lower grade form of acoustic energy (e.g. lower energy density), or that would convert the energy in the ultrasound waves into waste heat.

The ultrasonic horn can also be configured so that its shape is not intended to cause any increase in the amplitude of the ultrasound waves, but instead it is acoustically transparent. Such an acoustically transparent horn is intended to neither reduce nor increase the conversion efficiency of electrical to mechanical energy. The embodiments of the present invention illustrated in Figures 1 and 2 illustrate a single ultrasonic nebulizer module for simplicity of explanation. In practical application of the invention it is likely that multiple ultrasonic nebulizer modules will be fitted to each grow bed.

In a first preferred embodiment of the aeroponics apparatus the output tip of the ultrasonic horn is located within an aperture that passes through the wall of the reservoir, such that in use of the apparatus, the output tip is in contact with the liquid or solution contained within the reservoir. This is advantageous because the liquid or solution within the reservoir is able to provide cooling to the ultrasonic transducer via the ultrasonic horn, although this is a secondary, reduced, cooling effect. The ultrasonic horn can also act as a heatsink, for example by being connected to a metal outer casing of the ultrasonic nebulizer module, whereby heat is radiated into the aerial environment. This allows a heating, ventilation and air conditioning system can provide the primary source of cooling. In addition, the number of interfaces within the ultrasonic nebulizer and between that nebulizer and the rest of the system is minimised and thus the amount of attenuation and reflection of the ultrasound waves is minimised. The ultrasonic horn may be a close fit within the aperture or there may be an interference fit. Alternatively, it may be beneficial to provide an acoustic reflecting material between the ultrasonic horn and the wall of the reservoir to ensure that the amount of ultrasound transmitted to the liquid or solution is maximised.

According to a second embodiment of the present invention the output tip of the ultrasonic horn is in contact with the external side of the wall of the reservoir. This provides an advantage

because it avoids making a hole in the wall of the reservoir which has the potential to compromise the water-tightness of the reservoir.

In the apparatus of the second embodiment the output tip of the ultrasonic horn is preferably located within a recess extending from the external side of the wall of the reservoir.

5 Furthermore, the thickness of the wall of the reservoir adjacent to the recesses is a small fraction of the average thickness of the wall of the reservoir. It is advantageous to keep the thickness of the wall of the reservoir adjacent to the ultrasonic horn at a minimum thickness to reduce attenuation of the ultrasound waves.

Preferably, the aeroponics apparatus comprises a switching circuit that can supply electrical
10 power to the ultrasonic nebulizer module or that can remove that supply of electrical power to the ultrasonic nebulizer module.

Preferably, the reservoir is in the form of a tray having a bottom wall and at least one side wall protruding upwardly from the bottom wall.

Preferably, the ultrasonic horn is made from a metal such as an aluminium alloy or a titanium
15 alloy. A suitable metal will have a low acoustic loss and a high fatigue strength.

Preferably the ultrasonic horn is adhesively bonded to the ultrasonic transducer. An adhesive fixing has been found to be preferable for the connection between the ultrasonic horn and the ultrasonic transducer because mechanical fixings, such as threaded arrangements are more likely to change the acoustic properties of the transducer and/or reduce the intensity of the
20 ultrasound. Adhesives such as two-part epoxy resins have good acoustic properties and can also provide the desired level of thermal conductivity. However, it is possible to utilise a mechanical fixing.

Preferably, the longitudinal length of the ultrasonic horn is one quarter of, or an odd multiple of one quarter of, the wavelength of the ultrasound waves that, in use, travel within the
25 ultrasonic horn (the wavelength of the ultrasound changes as it passes through the different materials within the system) produced by the ultrasonic transducer. For example, the longitudinal length of the ultrasonic horn may be three-quarters of a wavelength. This is advantageous because it reduces the destructive interference caused when a portion of the sound wave undergoes internal reflection at the interface between the output tip of the
30 ultrasonic horn and the nutrient solution. The ultrasound waves reflected back into the body of the ultrasonic horn from the output tip interact constructively with the other ultrasound waves. Such an ultrasonic horn would be acoustically transparent.

Alternatively, the longitudinal length of the ultrasonic horn is one half, or an odd multiple of one half of, the wavelength of the ultrasound waves that, in use, travel within the ultrasonic horn. Such an ultrasonic horn would be amplifying.

5 Preferably, the ultrasonic transducer is a poled piezoelectric transducer and the direction of poling is aligned with the longitudinal axis X-X of the ultrasonic horn.

Preferably, the liquid is a nutrient solution formed from a mixture of water and nutrients.

In an envisaged embodiment of the present invention the ultrasonic horn is formed integrally with the reservoir, for example if the reservoir were to be manufactured from aluminium and the ultrasonic horn formed or cast into a wall of the reservoir.

10 Preferably, the ultrasonic horn is a solid, one-piece, body and has an upper half that is of lower mass than a lower half, wherein the height of the upper half is the same as the height of the lower half.

15 Preferably, the ultrasonic horn is a solid, one-piece, body with a cylindrical upper half and a cylindrical lower half wherein the diameter of the upper half is smaller than the diameter of the lower half and wherein the upper half and the lower half are coaxially aligned.

Figure 1 is a schematic cross-sectional view of an aeroponics apparatus according to a first embodiment of the present invention;

Figure 2 is a schematic cross-sectional view of an aeroponics apparatus according to a second embodiment of the present invention; and

20 Figure 3 is a schematic view of four ultrasonic horn shapes for use in either the first embodiment or the second embodiment of the present invention.

Figure 1 illustrates an aeroponics apparatus 1, according to a first embodiment of the present invention, for use in an indoor farming system. The aeroponics apparatus 1 comprises a grow bed 3 to which an integrated ultrasonic nebulizer module 5 is attached by any suitable means, such as by an adhesive or by mechanical fixings. An electrical supply supplies electrical power to the integrated ultrasonic nebulizer module 5 and is switched on and off by a switching circuit 7. A variation circuit 8, that is located within the ultrasonic nebulizer module 5, can vary the electrical supply so that it is appropriate to the ultrasonic transducer being utilised. A plant support 9 is located above the grow bed 3.

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The grow bed 3 comprises a nutrient solution reservoir 11 within which is contained a nutrient solution 13, for example a mixture of water and plant fertiliser. The grow bed 3 has side walls 15 which support the plant support 9. The plant support 9 has a partially open construction and the plants 17 are supported by it and the plant roots 19 can grow through it into the root bed space 21.

The integrated ultrasonic nebulizer module 5 comprises an ultrasonic horn 23 adhesively bonded at the input end 25 of the horn 23 to a piezoelectric ultrasonic transducer 27 with a two-part epoxy resin adhesive. The ultrasonic horn 23 has a stepped profile in cross-section and a circular shape when viewed from above. The upper section 24 is in the form of a solid cylinder of smaller diameter than a lower section 26 that is also in the form of a solid cylinder. The upper section 24 and the lower section 26 are formed integrally, from the same material, such that the ultrasonic horn 23 is formed in one piece and such that the mass of the upper section 24 is lower than the mass of the lower section 26. The piezoelectric ultrasonic transducer has an exposed, resin coated, piezoelectric ceramic disc and it uses a PZT-4 piezoelectric crystal. The PZT-4 crystal exhibits the inverse piezoelectric effect, i.e. when it is exposed to an electric charge the material will change dimensions. When the piezoelectric crystal is supplied with an electrical supply having the form of a sine wave the piezoelectric crystal, and thus the piezoelectric transducer will oscillate at the frequency of that sine wave. The piezoelectric transducer 27 is poled such that its direction of vibration is along the longitudinal axis X-X of the piezoelectric transducer 27, so that when those vibrations are converted into ultrasound waves that pass through the ultrasonic horn 23 substantially all of the ultrasound waves propagate in the X-X direction and a minimised amount of energy is entrained in laterally directed ultrasound waves. The length of the ultrasonic horn 23 is one quarter of the wavelength of the ultrasound that travels within the ultrasonic horn 23. An outer casing 29 partially surrounds the ultrasonic horn 23 and the piezoelectric ultrasonic transducer 27 and the piezoelectric ultrasonic transducer 27 is compressed between the outer casing 29 and the ultrasonic horn 23. The piezoelectric transducer 27 is mechanically preloaded to pressures of 10-30 kPa to improve operational efficiency, e.g. through restricting energy losses.

The grow bed 3 is provided with an aperture 31 in the bottom wall 33 of the reservoir 11 and the ultrasonic horn 23 is aligned with the aperture 31 such that its output tip 35 is located flush with the inside surface of the bottom wall 33. The ultrasonic horn 23 is a close fit with the aperture 31 and the fit may even be an interference fit. A seal 37 is provided so that the reservoir is watertight.

The switching circuit 7 has a mechanical relay (not shown) which is used to supply electrical power to the ultrasonic nebulizer module 5 or to remove that supply of electrical power. The mechanical relay can be commanded by farm control software, such as LettUs Grow's Ostara® software.

5 In use, when it is desired to supply water and nutrients to the roots of the plants via an aerosol, the switching circuit 7 is operated by the farm control software to provide a supply of electrical power to the variation circuit 8. The variation circuit 8 changes the frequency of the supplied electrical supply to a frequency that matches the inherent resonant frequency of the piezoelectric transducer 27 (i.e. ~1.7MHz), and provides that electrical supply, with the
10 specified electrical supply waveform, to the piezoelectric transducer 27.

The piezoelectric transducer 27 converts the electrical energy in the electrical power supply to ultrasound waves. The ultrasound waves pass into the input end 25 of the ultrasonic horn 23, across the adhesive bond interface between the ultrasonic horn 23 and the transducer 27. The ultrasound waves spread through the ultrasonic horn 23 towards the output tip 35, along
15 the longitudinal axis X-X. The ultrasonic horn 23 amplifies, i.e. increases the amplitude of, the ultrasound waves produced by the piezoelectric ultrasonic transducer 27.

When the ultrasound waves reach the output tip 35 they are then transmitted across the interface between the output tip 35 and the nutrient solution. The ultrasound waves then spread through the nutrient solution until they reach the surface of the nutrient solution. The
20 high pressure of the ultrasound waves causes a column of nutrient solution to extend from the surface. Surface acoustic waves on the column stimulate capillary wave motions to create the aerosol.

When sufficient aerosol has been created for the purposes of supplying water and nutrients to the roots of the plants then the switching circuit 7 turns off the electrical supply to the
25 piezoelectric transducer 27, such that the generation of ultrasound waves ceases.

Figure 2 illustrates an aeroponics apparatus 201, according to a second embodiment of the present invention, for use in an indoor farming system. The second embodiment shares many features with the first embodiment and those shared features are referenced utilising the same reference numerals as for the first embodiment, but pre-fixed with the number 2. In the second
30 embodiment there is no aperture in the bottom wall 233 of the reservoir 211. Instead, a recess 251 has been provided in the wall 233, such that the thickness of the wall 233 at the recess 251 is reduced. The ultrasonic horn 223 is located within the recess 251.

Figure 3 illustrates four possible forms of the ultrasonic horn 23, 223 for use in the first and second embodiments. Figure 3(a) illustrates a conical horn, Figure 3(b) an exponential horn, Figure 3(c) a stepped horn and Figure 3(d) a cylindrical horn. The ultrasonic horns 23 are all formed as a one-piece solid from a single material and they can be thought of having an upper half and a lower half, wherein the height of the upper half is h_1 and the height of the lower half is h_2 and h_1 is equal to h_2 .

Figures 3(a), 3(b) and 3(c) illustrate that the mass of the upper half of the ultrasonic horns, m_1 , is lower than the mass of the lower half of the ultrasonic horn, m_2 .

In use, the conical, exponential and stepped horns 23a, 23b and 23c respectively, cause an increase in the amplitude of the ultrasound waves produced by the ultrasound transducer 27, 227 when it is attached to the input end 25.

Figure 3(d) illustrates that, for the cylindrical ultrasonic horn 23d the mass of the upper half m_1 , is the same as the mass of the lower half m_2 .

In use, ultrasound waves are produced by the ultrasound transducer 27, 227 and they are passed into the ultrasonic horn 23d, when the transducer 27, 227 is attached to the input end 25 of the ultrasonic horn 23d. The cylindrical horn 23d does not cause an increase in the amplitude of the ultrasound waves. The amplitude of the ultrasound waves remains the same as they pass through the ultrasonic horn 23d. The cylindrical horn 23d has a longitudinal length that is one quarter, or an odd multiple of one quarter, of the wavelength of the ultrasound waves travelling through the horn 23d. This results in an ultrasonic horn 23d which is acoustically transparent.

CLAIMS

1. An aeroponics apparatus (1,201) comprising a grow bed (3,203) with a reservoir (11,211) for containing a liquid or a solution and an ultrasonic nebulizer module (5,205) attached to the grow bed (3,203), the ultrasonic nebulizer module (5,205) comprising an
5 ultrasonic horn (23,223) having an input end (25,225) connected to an ultrasonic transducer (27,227), in which the ultrasonic transducer (27,227) is between the ultrasonic horn (23,223) and an outer casing (29,229) which partially surrounds the ultrasonic horn (23,223) and the ultrasonic transducer (27,227), and an output tip (35,235), in which the ultrasonic horn (23,223) is in contact with a wall (33,233) of the reservoir (11,211).
- 10 2. An aeroponics apparatus (1,201) according to Claim 1, in which the output tip (35,235) of the ultrasonic horn (23,223) is located within an aperture (31,231) that passes through the wall (33,233) of the reservoir (11,211), such that in use of the apparatus (1,201), the output tip (35,235) is in contact with the liquid or the solution contained within the reservoir (11,211).
3. An aeroponics apparatus (201) according to Claim 1, in which the output tip (235) of the
15 ultrasonic horn (223) is in contact with an external side of the wall (233) of the reservoir (211).
4. An aeroponics apparatus (201) according to Claim 3, in which the output tip (235) of the ultrasonic horn (223) is located within a recess (251) extending from the external side of the wall (233) of the reservoir (211).
- 20 5. An aeroponics apparatus (201) according to Claim 4, in which the thickness of the wall (233) at the recess is reduced.
6. An aeroponics apparatus (1,201) according to any preceding claim, further comprising a switching circuit (7,207) that can supply electrical power to the ultrasonic nebulizer module (5,205) or that can remove that supply of electrical power to the ultrasonic nebulizer module
25 (5,205).
7. An aeroponics apparatus (1,201) according to any preceding claim, in which the reservoir (11,211) is in the form of a tray having a bottom wall (33,233) and at least one side wall (15,215) protruding upwardly from the bottom wall (33,233).

8. An aeroponics apparatus (1,201) according to any preceding claim, in which the ultrasonic horn (23,223) is made from a metal.
9. An aeroponics apparatus (1,201) according to any preceding claim, in which the ultrasonic horn (23,223) is adhesively bonded to the ultrasonic transducer (27,227).
- 5 10. An aeroponics apparatus (1,201) according to any preceding claim, in which the ultrasonic horn (23,223) has a longitudinal length running from the input end (25,225) to the output tip (35, 235), in which the longitudinal length of the ultrasonic horn (23,223) is one quarter of, or an odd multiple of one quarter of, the wavelength of the ultrasound waves that, in use, travel within the ultrasonic horn (23,223).
- 10 11. An aeroponics apparatus (1,201) according to any of Claims 1 to 9, in which the ultrasonic horn (23,223) has a longitudinal length running from the input end (25,225) to the output tip (35, 235), in which the longitudinal length of the ultrasonic horn (23,223) is one half, or an odd multiple of one half of, the wavelength of the ultrasound waves that, in use, travel within the ultrasonic horn (23,223).
- 15 12. An aeroponics apparatus (1,201) according to any preceding claim, in which the ultrasonic transducer (27,227) is a poled piezoelectric transducer (27,227) and the direction of poling is aligned with a longitudinal axis X-X of the ultrasonic horn (23,223).
13. An aeroponics apparatus (1,201) as claimed in any preceding claim, in which the solution is a nutrient solution formed from a mixture of water and nutrients.
- 20 14. An aeroponics apparatus (1,201) according to any of Claims 1, 2 and 6 to 12, in which the ultrasonic horn (23,223) is formed integrally with the reservoir (11,211).
15. An aeroponics apparatus (1, 201) according to any preceding claim, in which the ultrasonic horn (23, 223) is a solid, one-piece, body and has an upper half (24, 224) that is of lower mass than a lower half (26, 226), in which the height of the upper half is substantially
25 the same as the height of the lower half.
16. An aeroponics apparatus (1, 201) according to any preceding claim, in which the ultrasonic horn (23, 223) is a solid, one-piece, body with a cylindrical upper half (24, 224) and a cylindrical lower half (26, 226) in which the diameter of the upper half (24, 224) is smaller

than the diameter of the lower half (26, 226) and in which the upper half (24, 224) and the lower half (26, 226) are coaxially aligned.