

TECHNICAL REPORT



Ultrasonics – Conditioning of water for ultrasonic measurements

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Ultrasonics – Conditioning of water for ultrasonic measurements

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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FOR ULTRASONIC MEASUREMENTS****FOREWORD**

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IEC 62781, which is a technical report, has been prepared by IEC technical committee 87: Ultrasonics.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
87/494A/DTR	87/507/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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INTRODUCTION

Many ultrasonic measurements are conducted in water, as it provides an inexpensive and readily available medium with characteristic acoustic impedance comparable to biological tissue. However, basic tap water is far from optimum for ultrasonic measurement as it contains many dissolved, absorbed and suspended contaminants. Measurements can be affected in many ways by these impurities. For example:

- dissolved gases readily dissociate from the water in the presence of high rarefactional pressures or heat giving rise to bubble formation. These bubbles not only are unwanted point reflectors but also increase the likelihood of cavitation.
- dissolved ionic components result in a raised conductivity of the water, which in turn can affect the measured output from some unshielded hydrophones. Furthermore experimental equipment left in an ionic solution for any period of time will gradually develop a layer of deposit (e.g. calcium carbonate) on its surface.
- biological activity within an untreated water tank will result in the creation of an unpleasant film on all available surfaces. If left long enough this biological activity will result in an undesirable environment for the operator and may also be a health hazard.

To minimize these effects it is necessary to undertake a water treatment process.

These problems are well known and many IEC standards have sought to address these issues, often by means of an informative annex. This technical report aims to provide a unified resource for operators wishing to establish a water treatment process for ultrasonic measurements. This technical report discusses each of the stages within a water treatment process and provides examples of suitable treatment methods.

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ULTRASONICS – CONDITIONING OF WATER FOR ULTRASONIC MEASUREMENTS

1 Scope

This Technical Report describes methods:

- for degassing water to be used in ultrasonic measurements,
- to decrease the ionic content of water to be used in ultrasonic measurements,
- to decrease the biological content of water to be used in ultrasonic measurements,
- to reduce the suspended particulate content of water to be used in ultrasonic measurements.

This technical report is applicable to all measurements of ultrasonic fields where water is the transmission medium. The quality and treatment methods for water used within a radiation force balance (RFB) may be different from that required for hydrophone based acoustic measurements. Chemical based methods of water treatment (e.g. algacides) may be appropriate for these applications. However, in this document, chemical means are noted but appropriately discouraged for acoustic pressure/intensity measurements.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62127-1, *Ultrasonics – Hydrophones – Part 1: Measurement and characterization of medical ultrasonic fields up to 40 MHz*

3 Dissolved gases

3.1 General

Tap water is often super-saturated with dissolved gases (although not in the same relative quantities as in air). Bubbles can be a cause of major experimental problems since they act as near perfect reflectors of ultrasound. This can perturb the ultrasonic field being measured. Also, if a bubble forms directly in front of the active element of a hydrophone it will prevent any propagating ultrasound from being measured by that hydrophone. Finally acoustic pressures greater than approximately 100 kPa can cause cavitation, i.e. they can bring bubbles out of solution and it is well established that measurements can be strongly affected by acoustic cavitation. Trapped gas on particulate is also a significant source of cavitation and removal of suspended particulates is considered in Clause 6.

Cavitation is the growth, oscillation and collapse of previously existing gas- or vapour-filled micro-bubbles in a medium. This will result in the production of spurious acoustic signals both below and above the driving frequency (for stable and inertial cavitation respectively). Particular care should be taken to avoid inertial cavitation as bubble collapse is a particularly destructive event. If such a collapse happens on the surface of a hydrophone, damage to the hydrophone may occur. It is useful to note that macroscopic bubbles are visible to the naked eye. However, microscopic bubbles may be much harder to visually detect, and can be just as much of a problem. There is thus a need to define means of obtaining a suitable medium in which the effects of cavitation are minimized.

A measurement method to detect the onset of cavitation is described in [1,2]¹. Specifically, the onset of inertial cavitation is often characterized by the presence of the sub-harmonic of the fundamental operating frequency or additional broadband noise. Examples of acoustic spectra acquired using a needle and membrane hydrophones is presented in [3,4].

3.2 Chemical methods

3.2.1 General

Whilst chemical methods of removing dissolved gases can be very effective both in terms of initial degassing rate and rate of subsequent re-gassing, they have a number of drawbacks. Firstly, chemical methods tend to be single gas specific (e.g. removing oxygen only). Secondly, they involve the addition of ionic content to the water; this is in complete contradiction to the attempts in Clause 4 to deionise the water. Thirdly, a number of chemical methods of degassing require the use of strong reducing agents that can be both hazardous to the user and may cause damage to experimental equipment. Finally, disposal of chemically treated water needs to be handled with care to avoid potential environmental harm.

3.2.2 Addition of sodium sulphite

Sodium sulphite (Na_2SO_3) can be added to water to act as an oxygen scavenger. Water saturated with oxygen at 20 °C will contain about 9 mg/l oxygen. To bind the oxygen 0,5 g/l sodium sulphite is needed. The use of Na_2SO_3 for degassing water results in sodium sulphate (Na_2SO_4).

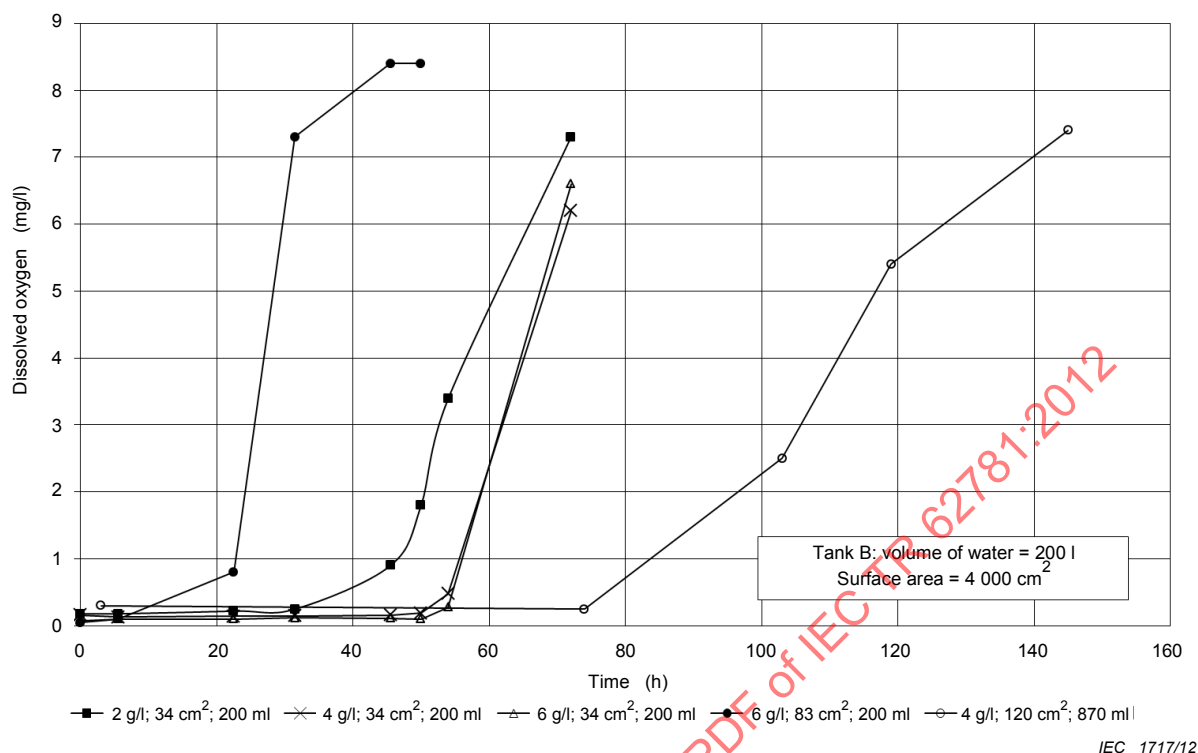
As an example water has been prepared to which Na_2SO_3 is added to give a solution of 0,4 mass % Na_2SO_3 . The O_2 -content of this water type stays < 4 mg/l during a long period of time, see Figure 1. The speed of re-gassing strongly depends on the dimensions of the water tank. Re-gassing periods > 150 h are observed in tanks with greater dimensions.

The speed of sound in a fluid, c_L , is given by

$$c_L = \sqrt{\frac{K}{\rho}}, \quad (1)$$

where K is the bulk modulus of the fluid and ρ is its density. The change in density after adding Na_2SO_3 in the concentration listed above is < 1 %, and the change in bulk modulus is even smaller. Therefore the change in sound speed is negligible. The electrical conductivity using a mixture of 4 g/l Na_2SO_3 is 5,1 mS/cm.

¹ Numbers in square brackets refer to the Bibliography.



Measurements started directly after filling the glass. Water temperature (22 ± 1) °C.

Figure 1 – Dissolved oxygen concentration as a function of time for 2, 4 and 6 g/l of sodium sulphite in de-mineralised water and for different surface areas and volumes of water

There are some effects on metals like aluminium and nickel (Na_2SO_3 will act like a base). For example, after 2 h in the solution, a transducer with an aluminium front surface will be corroded somewhat. It is therefore recommended that immersion of these types of metals is carried out over as short a time period as possible.

3.3 Physical methods

3.3.1 General

Unlike chemical degassing methods, physical degassing methods do not add ionic content to the water nor are they single gas specific. A good overview of a selection of physical degassing methods is presented in [5].

3.3.2 Vacuum degassing

When a vacuum (2 kPa to 2,5 kPa) is applied to a standing body of water, the reduced pressure will prevent dissolved gases from remaining in solution. Under these conditions the water will appear to boil as the gas bubbles rapidly expand and then break at the water surface. After a period of 24 h, levels of dissolved oxygen can be as low as 1 mg/l.

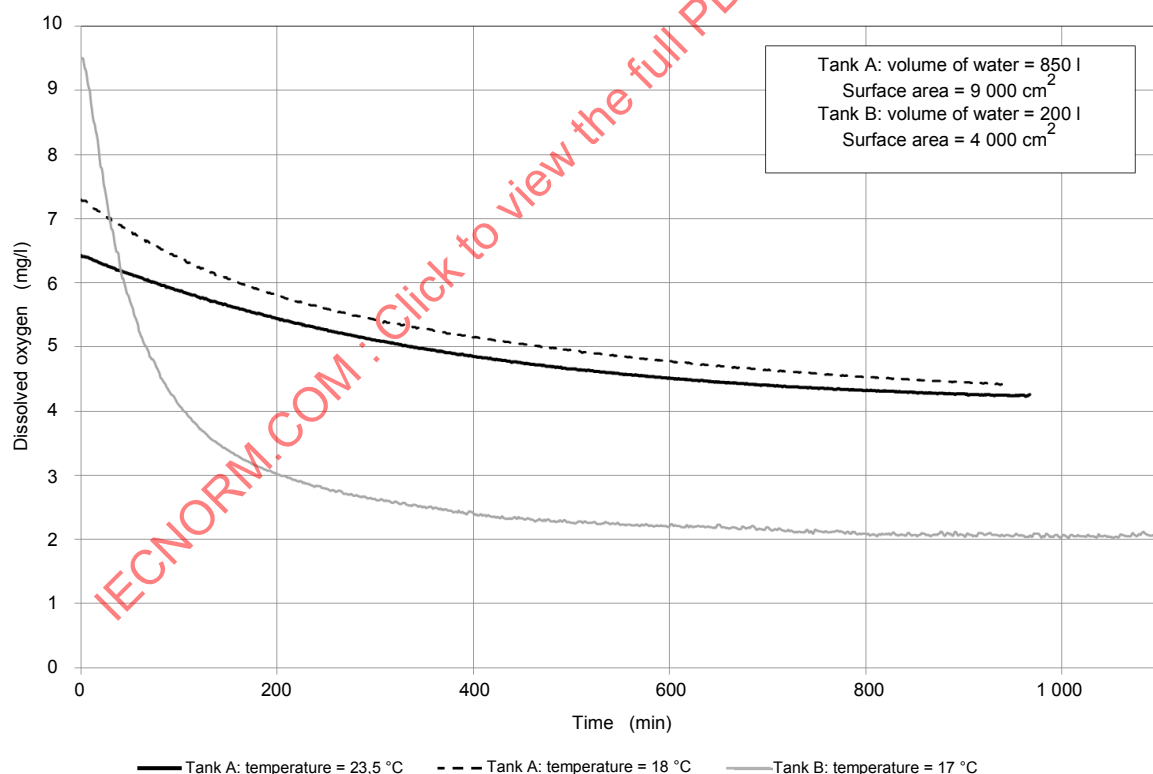
3.3.3 Reduced pressure recirculation

Many water conditioning systems employ a pump to circulate water through the treatment system. Choosing a high volume pump and using a small modification at the inlet allows the pump to serve a dual purpose. A reduced pressure degassing system [5] can easily be prepared by attaching a reinforced pipe/rigid tube to the inlet of a high volume pump. A flow

restrictor is then attached to the other end of the pipe/tube and placed within a reservoir of water to be treated. Finally the outlet of the pump is connected via simple tubing back into the reservoir. The combined effect of the high flow rate pump and the flow restrictor is to form a partial vacuum in between the two. In this low pressure environment, gas content within the water is unable to remain dissolved, and bubbles form. Nucleation effects then tend to cause multiple smaller bubbles to coalesce into fewer larger bubbles. Even when normal pressure is restored, the surface area-to-volume ratio of these larger bubbles is such that it inhibits their reabsorption into the water. Therefore the output from the pump is a stream of water containing larger bubbles.

When returned to the reservoir, these larger bubbles simply float to the water's surface and are released to the surrounding environment. The quantity and size of bubbles in the output stream can also be used as a qualitative measure of the amount of dissolved gas still remaining within the water reservoir. If required, the water tank can be used as the reservoir, although a separate vessel can also be used.

It is instructive to note that high filling points should also be avoided since they frequently become exposed as the water level within the tank reduces due to evaporation. When this happens, the cascade of water from the inlet traps air and drives bubbles into the body of the tank. Therefore both inlet and outlet points should be as low as possible in the water tank to prevent this type of enhanced gas reabsorption mechanism. The effectiveness of this method depends upon the pressure drop that can be achieved within the inlet hose, but with the appropriate configuration oxygen levels of 2 mg/l to 3 mg/l can be achieved as can be seen in Figure 2.



IEC 1718/12

Figure 2 – Dissolved oxygen concentration in water as a function of time during reduced pressure recirculation degassing

Within Figure 2, it is instructive to note that the larger volume tank degasses at a much slower rate than the smaller tank.

3.3.4 Degassing contactors

Another method of using the recirculating pumps prevalent in acoustic tanks is to include a commercially available degassing contactor tube in the fluid path. These degassing tubes are used in many industries for both gassing and degassing liquids on both a commercial and laboratory scale.

The tube consists of a bundle of several thousand hollow hydrophobic fibres through which the fluid passes. The membrane of these fibres is physically permeable to gasses of the order of CO_2 or smaller, so O_2 and N_2 also pass through these membranes.

Through partial pressure, the force of the water through the membrane is sometimes enough to de-gas to an acceptable level. However, with the application of a small or moderate vacuum to the shell side of the tube, either from a low cost pump or Venturi system, dissolved oxygen levels in the 1-3 PPM levels can easily be achieved on a single pass through the device at flow rates of 500 to 3000 ml/min.

Maintenance of these devices is very low, especially with the addition of a particle filter ($0,45 \mu\text{m}$ or so) to prevent clogging of the orifices on the membrane over time. Some water vapour also passes through the membrane which can be collected in a fluid trap before the vacuum pump.

3.3.5 Boiling

Boiling the water for a specified period of time is also a suitable method for degassing. Table 1 presents results that can be obtained using three different procedures.

The O_2 concentration is given after boiling and cooling down in a water reservoir to below 23°C . The cooling down period depends on how fast the water in the reservoir is being refreshed and on stirring.

Table 1 – Conditions for degassing by boiling

Boiling period (minutes)	5	10	20
Start O_2 concentration (mg/l) before boiling	7,2	7,8	8,0
End O_2 concentration at about 23°C (mg/l)	1,7	2,0	3,1
Period between end of boiling ($T = 100^\circ\text{C}$) and cooling down till $T = 23^\circ\text{C}$ (minutes)	24	35	28
Remarks	Not stirred	Not stirred	Very quietly stirred

From Table 1 the following conclusions can be drawn:

- boiling for as short as 5 min sufficiently degasses the water;
- stirring (even very quietly) in the cooling period has a strong, undesired influence on oxygen content of the water;
- the cooling period does not apparently influence the oxygen content, as long as it is shorter than 35 min.

3.4 Verification methods

3.4.1 General

An accurate determination of total dissolved gas content would involve multiple measurements to quantify the concentration of each individual soluble gas. At the time of preparation of this document, meters capable of multiple gas content measurement were not readily available.

An alternative approach is to consider the gaseous concentration of a single gas only, and assume that all dissolved gases had been reduced to similar concentration levels. Clearly this assumption is invalid if single-gas specific methods have been used. Numerous dissolved oxygen meters are commercially available and they operate upon either electrical or optical principles.

3.4.2 Electrical verification methods

Electrical methods of measuring dissolved oxygen content rely upon the diffusion of oxygen across a permeable membrane. Behind the membrane, two electrodes are immersed in an electrolyte solution and as oxygen diffuses across the membrane it is subject to chemical reduction at the cathode. However, the consumption of oxygen is a limitation of this method since the process itself is reducing the concentration of the gas being measured. Unless the water immediately in front of the electrode head is circulated (e.g. by stirring), this method leads to erroneous values due to oxygen consumption in the volume of water immediately adjacent to the measurement head.

3.4.3 Optical verification methods

Optical methods of measuring oxygen concentration work by quantifying the luminescence of a sensor on the measurement probe. The presence of oxygen will suppress the luminescence, but importantly, oxygen is not consumed in this process. Therefore optical methods of quantifying dissolved oxygen content do not require stirring (although this may be advantageous to ensure even distribution of gas content throughout the volume of water being measured). Since stirring is not essential, optical methods can provide long timescale in-situ measurements. Furthermore many meters come with data logging facility so that oxygen content and other data (e.g. timestamp, temperature, etc.) can either be stored for subsequent processing, or transmitted across a network for remote analysis.

3.5 Re-gassing

Any standing body of water exposed to air at an open surface or through a gas permeable membrane/wall, will naturally reabsorb water-soluble gases until saturation levels are reached. The rate of re-gassing will depend on a number of factors, but temperature, water circulation and the ratio of exposed surface area of water to water volume all require consideration. An example of this can be found in Figure 3.

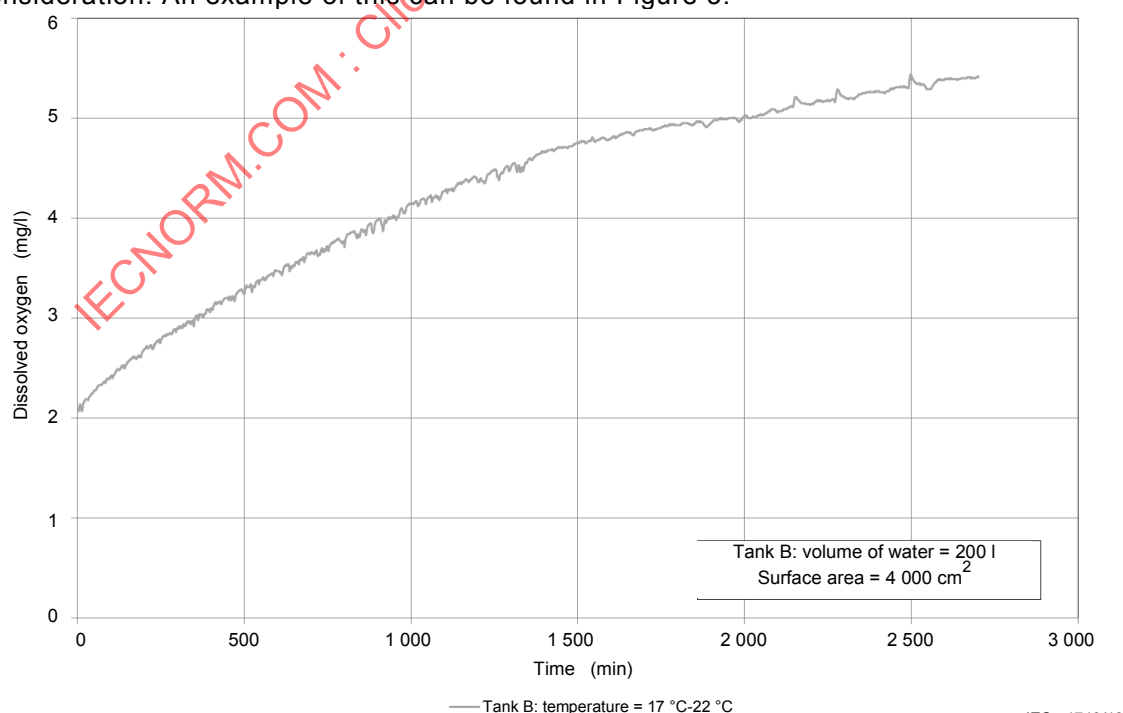


Figure 3 – Re-gassing profile for a body of water following reduced pressure recirculation degassing

Various solutions have been proposed to reduce the surface area through which reabsorption can occur. A low density, or voided polymer film (e.g. bubble-wrap packaging) addresses the problem of the film sinking in the tank. However, film layers have to be removed before the tank can be used. Moreover, in time the voids can flood and the film layer tends to sink. A better alternative is to employ a method that both floats and can be left in place when the tank is in use even when an automated hydrophone positioning system is in use. In this context, a layer of polypropylene (or similar) balls floated on the water surface provides an excellent solution: they reduce surface area, move easily out of the way of any objects moved through the tank, and due to their spherical surfaces serve to minimise the specular water surface reflection.

4 Dissolved ionic content

4.1 General

Tap water can often contain significant amounts of dissolved ionic material. The most obvious side effect of this is an increase in the water conductivity, which can result in a “low resistance” path between electrodes of some co-planar membrane hydrophones. The increased conductivity can provide a conduction path for electromagnetic interference, which will increase the noise received by the hydrophone. There is also the likelihood that these dissolved solids will be deposited onto any objects left within the water. This is a particular problem in “hard-water” areas where chalky deposits can build up on anything left within the tank. If hydrophones are subject to such deposits then there will be a gradual reduction in the sensitivity of the hydrophone as the thickness of the contamination increases.

IEC 62127-1, detailing the use of ultrasonic hydrophones, recommends a conductivity of no more than 5 $\mu\text{S}/\text{cm}$ for measurements involving electrically unshielded membrane hydrophones.

4.2 Chemical methods

4.2.1 General

Chemical methods of deionising water only add hydrogen or hydroxide ions into the water. This is acceptable, and contrasts with most other chemical methods of water treatment listed in this document.

4.2.2 Ion exchange devices

These devices contain ion exchange resins that contain a mixture of anionic and cationic reagents that replace all dissolved ionic content with their respective hydrogen or hydroxide ions, which when combined, result in pure water. The initial equipment costs for an ion exchange system are relatively low, but the exchange resin is a consumable item that must be replenished.

As with all ion exchange systems, higher levels of ionic content in the input water will result in short life spans of the ion exchange resin. As the ion exchange resin approaches the end of its useful life, the conductivity of the treated water will increase. It is therefore advisable to have a means of monitoring the output water quality from the ion exchange system. The ion exchange resin should be reactivated/replaced when acceptable conductivity levels have been compromised. This process is suitable for infrequent use as running costs (due to resin replacement) can be expensive if larger quantities of water are required.

4.3 Physical methods

4.3.1 General

As with all other physical methods described in this document, the physical methods of removing ionic content do not add further contaminants to the water being processed.

4.3.2 Distillation

By boiling, and then separately re-condensing water, any dissolved solids are left on the inner surfaces of the still and the emerging water has a lower ionic content. This ionic content will eventually build-up as a layer of lime scale and thus the still should undergo regular maintenance descaling. Whilst the capital cost of a still is small, distilled water is not as effective as deionization and water must often be double or triple distilled before it approaches the purity of an ion exchange resin. This process is best suited to the production of larger volumes of water when poorer levels of deionization are acceptable.

In many countries, equipment capable of distilling liquids is subject to legal licensing requirements (control of alcohol legislation) so appropriate advice should be sought prior to the installation and operation of a still.

4.3.3 Reverse osmosis

Reverse osmosis (RO) uses a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting other ions and contaminants from passing. Elevated pressure is used on the high solute side of the membrane to overcome the osmotic pressure. Reverse osmosis systems are often quite expensive, but have relatively low running costs. This process is best suited for applications that demand large volumes of very well deionised water, and can tolerate the high initial equipment costs.

As a by-product of maintaining the appropriate osmotic pressure large quantities of waste water are produced. Whilst this water will not have been contaminated by the process, it is not of use and therefore needs to be appropriately disposed of. Clearly there are both financial and environmental costs associated with this aspect of RO systems

4.4 Verification methods

Dissolved ionic content can be readily quantified with a conductivity meter. Conductivity meters tend to take two forms: probe, and inline systems. Probe conductivity meters have a series of electrodes that are immersed in the water. An electrical current is passed across one pair of electrodes, whilst the potential across the second pair of electrodes is monitored. The conductivity is then calculated from the applied current and the measured potential.

Inline systems often use an inductive coupling method that incorporates a water-filled channel as the secondary windings on a transformer. By applying a known electrical signal to the primary winding and monitoring the signal developed on the secondary, the conductivity of the water can be calculated.

Water conductivity is highly temperature dependent so electrical conductivity meters often contain temperature measurement capabilities as well. As with optical verification of degassing, many conductivity meters incorporate data logging facilities.

4.5 Reionization

Any object placed within the water tank is a potential source of ionic content. However, most of the methods taken to prevent water damage to apparatus also help to reduce reintroduction of ionic content. Such procedures include:

- use of stainless steel components, but no mild steel/iron,
- use of aluminium components as long as they are anodised to prevent corrosion,
- use of plastic components as long as they do not contain process oils that can leach from the plastic into the water.

5 Biological content

5.1 General

Whilst not explicitly mentioned in ultrasonic measurement standards, prevention of biological growth is an important issue. The most obvious side effect of biological activity within a water tank is that the water tends to develop a cloudy yellow/green appearance, and can start to smell. A slimy film tends to accumulate on the surfaces of any items that are exposed for long periods. These deposits will serve to compromise the performance of a hydrophone in the same manner as calcification (see Clause 6). Most importantly, however, is that bacterial growth within the water can be a health risk to users of the water tank.

One of the principle sources of biological water contaminants is human contact, particularly when setting up or removing measurement and equipment (e.g. transducers, hydrophones, scattering targets) within the water tank. In some laboratories it may be practical to issue operators with clean, waterproof gloves to minimise this source of contamination. Similarly, it may also be possible to use alcohol impregnated wipes, to disinfect equipment surfaces prior to immersion. Both of these methods are effective in preventing biological agents entering the water; however, it is understood that these may not be measures that are universally practical and hence applicable.

Removal of dissolved gases and solutes (see Clauses 3 and 4) will serve to slow down biological growth by reducing the available food sources. However these methods will not kill off any bacteria already present, and a selection of methods for bacteria removal is given below. Another important consideration is that of the measurement tank position, particularly in relation to sources of heat and light. A measurement tank in a warm location will see greater biological growth than one in a cooler environment. Furthermore, biological activity that is reliant upon photo-synthesis will prefer a site with plenty of light. A measurement tank placed in a carefully considered location (and definitely away from a sunny window) will exhibit much lower biological growth rates than an inappropriately placed one. When not in use, the tank can also be covered with a dark cloth to further reduce biological growth.

As with degassing methods (Clause 3), it is important to note that chemical methods for controlling biological growth are often in contradiction with the attempts to achieve deionised water. Therefore if low conductivity water is required, it is better to use physical methods to control biological activity (e.g. UV filtration, 5.3.2) as opposed to the addition of chemical treatments.

5.2 Chemical methods

5.2.1 General

Whilst chemical methods for dealing with biological activity can be very effective, they involve the addition of ionic content to the water; this is in complete contradiction with the attempts in Clause 4 to deionise the water.

5.2.2 Addition of chlorine-based chemicals

Chlorine-based chemicals are commonly used to control biological activity in swimming pools. These chemicals are sometimes used as anti-bacterial agents in water tanks, although elevated concentrations of chlorine solutions can cause bleaching of fabrics. Furthermore prolonged skin exposure may lead to skin sensitisation and irritation for users of the tank.

5.2.3 Addition of copper-based chemicals

Anti-bacterial treatments based upon copper compounds are also widely available. They are used extensively in the marine industry as anti-fouling agents and there are some copper-based solutions that are designed for addition to swimming pools. Some of these compounds are based upon a combination of compounds that decay over a range of timescales. This is claimed to have the benefit that the specific concentration of each anti-bacterial agent is

continually changing as a function of time, and thus the bacteria are unable to become acclimatised and thus tolerant of a particular chemical environment.

However, it should be noted that copper solutions may react with other metals, and some metals (particularly aluminum) have an adverse chemical reaction with some copper-based chemicals. Given that a number of ultrasonic hydrophones incorporate thin gold electrodes, prolonged exposure of these hydrophones to copper-based chemicals may lead to a degradation of the electrode layer and thus a compromised hydrophone performance.

5.2.4 Addition of silver-based chemicals

Silver has been well-known to exhibit an anti-microbial behaviour with its medical uses dating back to the late 18th Century to aid the healing process; it can also inhibit fungal growth. Silver is insoluble in pure water, although some of its compounds (notably silver nitrate and silver fluorides) are readily water soluble. Consequently, silver powder is preferable to silver compounds as a means to control water-borne biological activity since pure silver will not compromise the conductivity of the water, and will not be removed by an ion exchange system. Clearly though, silver powder will be susceptible to removal by particulate filtration.

5.3 Physical methods

5.3.1 General

As with all other physical methods described in this document, the physical methods for removing biological content do not add further contaminants to the water being processed.

5.3.2 UV filtration

Ultraviolet (UV) filters, readily available from commercial sources, incorporate an ultraviolet light source surrounded by the water to be treated. Exposure to intense UV radiation kills all biological activity within the treatment vessel. There are several types of UV filters available. The majority of consumer systems are designed with a short wavelength to produce ozone which is the method of anti-microbial action. By choosing the correct wavelength of UV light bulb (250-270 nm) a more effective biological destruction can be accomplished. However, care must be taken to ensure that the rate of flow of water through the UV filter does not exceed the manufacturer's recommendations. If this occurs, the water does not receive a sufficient dose of UV radiation and incomplete/ineffective water treatment may result. For this reason care should be taken when incorporating a UV filter alongside a high flow rate pumping systems. Conversely, care must also be taken to ensure that the UV filter is not too powerful for the flow rate, as an undesirable increase in water temperature can occur. It is also worth noting that many commercial systems incorporate treatment vessels that are made of glass. These glass treatment compartments may not be capable of supporting reduced pressures, and thus should not be used where partial vacuums may be experienced (see reduced pressure re-circulation degassing).

5.3.3 Cavitation methods

Large-scale waste water treatment plants are introducing systems to disrupt and destroy biological organisms based upon high intensity ultrasonic fields in combination with aeration schemes. The aeration process deliberately introduces gas bubbles into the liquid being treated to seed acoustic cavitation. Whilst very effective at destroying bacterial growth these methods are typically implemented on an industrial scale. As yet small scale ultrasonic water treatment systems suitable for laboratory use do not appear to be widely available, if at all.

6 Suspended particulate content

6.1 General

Particulate suspended within water will act as scatterers of ultrasound. Various models have been used to estimate when the dimensions of a scatterer becomes sufficiently small so that

its interaction within an incident beam becomes negligible. Depending on the precise shape of the scatterer, dimensions in the range $\lambda/10$ to $\lambda/20$ are often assumed to the limit below which scattering is no longer an issue. Here λ is the acoustic wavelength in a liquid. Clearly then, when very high frequency ultrasonic content is expected, particular attention should be paid to sources of scattering, and filter sizes should be selected accordingly. It is important to note that this limitation may not be restricted only to devices with a high acoustic working frequency. Given the acoustic nonlinear propagation effects, it is likely that a system capable of 2nd harmonic imaging will also have significant energy at 3rd and maybe higher harmonics. With many commercial systems operating at working frequencies of 15 MHz (or more), harmonic components in the range 30 MHz to 40 MHz are increasingly common. Consequently scatterers of dimension below 2 μm may need careful consideration.

Suspended particles can also be sources of nutrient to bacteria/fungi. Furthermore, they provide additional surfaces on which biological growth can occur. Therefore, removal of suspended particulates inhibits both these opportunities for biological activity.

6.2 Physical methods

Particulate matter is best dealt with by means of simple particulate filters. A two-stage particulate filter is recommended with a larger filter mesh (e.g. 5 μm to 10 μm filter) followed by a finer filter (e.g. < 1 μm filter), both placed nearest the inlet side of the system. It should be noted that finer filters will limit flow rate and thus may have an impact on pump specification (and cost, as well as heating of the water). It should be noted that very fine mesh filters (< 0,45 μm) are commonly used in the analysis of fecal coliforms are impenetrable to bacteria of this size. Therefore, finer particulate filters may also be useful in the control of water-borne bacterial contaminants. However, if these bacteria have not already been killed, either through UV exposure or through the addition of appropriate chemical agents (see Clause 5) they will remain trapped in the filter where they are able to multiply. This can eventually lead to re-contamination of the water. Therefore, if they are to be used, particulate filters should be placed after UV filters.

All particulate filters will become blocked over time, and will eventually either impede the passage of water through them, or start to fail internally and release previously trapped particulate matter back into the water. Filters should therefore be visually inspected regularly (no more than three month intervals) and replaced when necessary.

6.3 Particulate re-contamination

Re-contamination of water with particulate matter comes in three principal routes: airborne, corrosion of permanent fixtures, borne by items temporarily introduced into the water (including the operator's hands). Consequently, appropriate inspection and/or control procedures should be established. If the water surface has a protection layer to reduce re-gassing rates (see 3.5) this can also reduce airborne contaminant. However, it is important to realise that airborne contaminant will instead accumulate on the protection layer. Therefore this layer will in time need to be replaced (in the case of a polymer film) or washed (in the case of polypropylene balls or similar).

7 Water temperature

7.1 General

Water temperature can have a significant effect on ultrasonic measurements, in both a direct and indirect manner. The most obvious direct effect is that speed of sound in water is temperature dependent so clearly calculations of acoustic intensity will be affected. More subtly though, thermal gradients (particularly if they occur within the acoustic path) may induce refraction and thus changes of beam direction and/or focussing.

When considering indirect effects it is instructive to recall that some designs of hydrophones have shown to receive sensitivity variations as a function of temperature. Similar comments in

the context of the transmit sensitivity of ultrasonic sources are equally applicable. Moreover, it has been seen that many of the other water conditioning issues mentioned in this document have a thermal dependence (e.g. degassing rates – see 3.3.3, biological growth rates – see 5.1).

The operator should therefore consider the impact of these thermal variations. It may be sufficient to simply monitor temperature changes within the measurement tank and apply any necessary corrective factors to results obtained. However, if metrological uncertainties require very tight control it may be more appropriate to consider whether a thermal management system (such as a combined heater/chiller unit) is necessary. Ensuring a uniform heat distribution through a large body of water within a tank can be challenging. Inevitably a re-circulating flow through the water is required and thus the effect of the turbulence on the acoustic measurements should be considered carefully. Another consideration is that some radiation force balances operate with small water volumes (50 ml) and so temperature increases can be rapid and even quite small sources of heat (diagnostic transducers) can be significant.

7.2 Thermal sources in an ultrasonic measurement tank

The most dominant effect governing water temperature in water tanks is the change in ambient temperature of the laboratory. Clearly in an air-conditioned building this variable is largely out of the operator's control, but also the total thermal range is likely to be limited. In contrast, a poorly insulated, non-air-conditioned building could exhibit significant daily thermal variation. However, there may be local thermal sources that directly affect the measurements. Of particular note is the rest of the equipment in the water treatment system. Whilst the details are highly equipment specific, pumps and UV filters can heat water several °C above ambient temperature (particularly in smaller tanks).

If very small volumes of water are in use (such as in an RFB measurement vessel), the ultrasonic transducer can often be a heat source. Particular care needs to be taken when undertaking RFB measurements incorporating acoustic absorbers on high power transducers. During measurement the significant majority of ultrasonic power emanating from the source transducer is deposited in the acoustic absorber. However, the absorber will then dissipate its heat into the water of RFB vessel. Given the high ultrasonic powers (sometimes in excess of 100 W) and the limited volume of water, large thermal rises (> 40 °C above ambient) are possible.

8 Examples of low-cost water treatment systems

8.1 Hydrophone measurement water tank

Within a hydrophone measurement environment, water conductivity is an essential consideration, and thus the inclusion of a means to deal with dissolved solids is high priority. The water treatment system shown in Figure 4 includes both an ion-exchange resin (and a conductivity meter to monitor the condition of the resin). Water degassing is achieved by means of the high volume pump and the inlet flow restrictor. Also included within the water re-circulation system are UV and two-stage particulate filters. All the water filtration methods are physical (rather than chemical) and thus the low conductivity introduced within the ion-exchange system is preserved.