TREATMENT OF WATER IN DOLPHINARIA

by S. H. Andersen, Mag. Marine Bio-acoustical Investigations, Strandvejen, Strib, 5500 Middelfart, Denmark.

Summary

A review on the principles of water treatment in dolphinaria. Filtertechniques, chlorination and its toxic consideration, pH control and flocculation are discussed. It is emphasized that a dolphinarium requires a higher standard and better control than an indoor swimming pool.

Introduction

Dolphinaria are now a common thing in many countries over the world. There are about 35 of them in Europe, including the United Kingdom. This has caused a high consumption of animals mainly because the mean survival time of the dolphins in captivity is shockingly low, resulting in, in connection with pollution (Dudok van Heel, 1972), an overfishing situation.
Most of the specimens come from an obviously separated population of bottle-nosed dolphins, *Tursiops truncatus* (Mont.), in the Mexican Gulf and the waters around Florida. The Department of Natural Resources, Talahassee, Florida, USA, has laid down the first State rules and guide lines for the catching, transportation an husbandry of dolphins. These only affect animals that are caught in their territorial waters but are drawn up to prevent the misuse of these wonderful animals.* The situation is serious and at the Symposium on Dolphins and Dolphinaria in Harderwijk, Holland, in February 1972, a resolution was addressed to European governments to request the making of laws for the total protection of marine mammals.
Besides pollution which has its influence on all marine mammals, accidental catching of dolphins in fish nets and the heavy toll caused by the modern methods in the tunny fishery are responsible for the marked decrease in the wild population of these cetaceans. Therefore we have to learn how to keep dolphins in captivity so that their life span and reproductive rate can be as in the wild. This may, in the future, urge governments to establish new dolphinaria or encourage the operation of already existing ones to continue. We have to teach others how to keep dolphins or the whole business will stop by itself.

* Editor's note: These rules have been overrun in the end of 1972 by a federal law in the U.S.A. protecting all marine mammals. Pending the development of rules and guide lines within the scope of this law all catching permits are forbidden generally and subject to specific hearings before being issued if issued at all.

The aim of this article is to discuss some principles of water treatment in dolphinaria based on the author's own experience with the harbour porpoise, *Phocoena phocoena,* the sparse information in the dolphin literature, personal communication with keepers of bottle-nosed dolphins and literature on treatment of water in public swimming pools.

The actual dolphinaria situation

About 10 years have elapsed since Europe got the first dolphinarium. In the USA the first dolphinarium was established in the late thirties. Still, very little is mentioned in the literature on how to keep dolphins in captivity and the obvious cause of this is most probably that economical interests have prohibited a free exchange of experience between the curators of the dolphinaria. The reason behind this is that it is still believed that keeping dolphins involves several important secrets.

This is a most regrettable development since there has been in general little progress in prolonging the survival time of captive dolphins. It is known that dolphins can live for more than 20 years in captivity but it is not unrealistic to consider one to two years as a mean life span for dolphins in most European dolphinaria. There are few dolphinaria in Europe that are really good ones. Most of them suffer from being run by personnel who have too little knowledge of the biology of the animals and the treatment of the water and often the installations are built in a way that is not suited for the holding of dolphins e.g. too little filter capacity or too small pools or both.

Many dolphinaria are constructed as if they were meant for a public swimming pool. Nothing is more wrong. Swimming pools have a cyclic load during 24 hours because they are in use only in daytime and even in this period there are short pauses during which the water can regenerate. The load is much more inferior to that in a dolphin pool. The visitors are newly washed, do not normally defecate and urinate in the water, they do not leave left overs from their meal in the water and they are only there for a short period. The chlorine concentration can be kept at higher levels and due to all the above mentioned factors the circulation rate can be kept low e.g. between 4 and 8 hours. Too many dolphinaria have been built after this scheme or even worse ones. Pools for dolphins are in fact much more difficult to maintain because of the constant load and the more sensitive inhabitants.

It is an astonishing amount of waste that comes from animals in a dolphin tank. Ridgway (1972) has calculated that one animal of 136 kg (300 lbs.) eating 6.6 kg (15 lbs.) of fish a day passes over 4 litres (1 gallon) of urine and about 1.4 kg (3 lbs.) of faeces per day. This gives us an idea of the pollution of the pool water in comparison to the public swimming pool situation. Füchs (1962) and Haag-Rück (1971) have calculated that about 0.05 litres of urine is passed into the water in a human swimming bath per person per 24 hours. The urine passed from a bottle-nosed dolphin is thus 80 times more. If we leave out of consideration the extra load on the water by the dolphins' faeces and food left-overs, 4 animals will pollute with the urine alone as much as 300 guests in a swimming bath per 24 hours, calculated on a basis of normal Danish conditions with a load of 1 guest per m^3 per 24 hours.

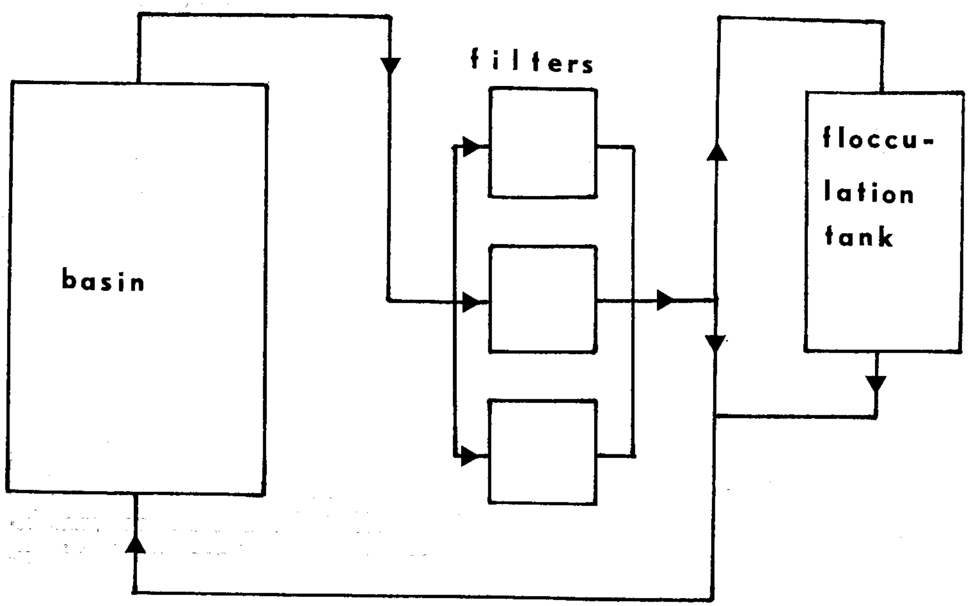

Fig. 1: Sketch of a water treatment plant for a dolphin pool, see text.

The ideal installation

An ideal dolphin plant is sketched in Fig. 1. The outlet water from the pool is led to vast, open sand filters with a slow filter rate e.g. 5 m^3 per hour per m^2 retaining the coarse particles. Some of the water is led to the next tank and mixed with a chemical precipitation agent e.g. aluminium sulphate, and allowed for sedimentation. The water is then slightly chlorinated, pH and salt adjusted and pumped back to the pool. The remainder of the water is pumped directly from the filters to the pool. The turnover of the whole water body ought to be about 1 hour and inlet and outlet systems should allow for a very efficient mix-up to avoid dead water. The system is expensive, requires well trained personnel and skillful constructors but it is ideal for the animals.

Principles of water treatment

Both sand and diatomaceous filters will only retain particles down to a certain size. Smaller particles and dissloved (organic) matter will pass through the filter to the pool and accumulate here and turn the water more and more green. If sufficient free chlorine is present and sufficient long reaction time is allowed for, the chlorine will break down the organic matter. Other compounds that pass the filter are the colloids which stay as negative charged particles. Due to their common negative charge they will stay suspended in the water and together with the chloramines dye the water. Thus an evil circle is closed which can be broken only by:

1. The addition of make-up water e.g. 5-10 per cent per day and release of a similar amount of water into the sewer. The chloramines and the colloids are thus diluted and the water is kept clean. This can be an expensive method in big plants due to the cost of water and salt and will inevitably give fluctuation in the pH and the chlorine concentrations.

2. Making the pool large in relation with the number of animals. This allows for a long reaction time for the chlorine and a smaller load on the water per m^3. As a rule of thumb 100 m^3 water is optimal for 2 harbour porpoises or 1 bottle-nosed dolphin or 1/10 of a Killer Whale!

3. Hyper chlorination. The animals are separated, e.g. each night, from the main part of the water body to which large quantities of chlorine are added. After proper reaction time dechlorination is effected. An extra pool containing a volume equal to e.g. 2/3 of the water can also be of good use but is expensive.

4. Flocculation. The addition of a flocculating agent will, through its colloidal nature, from larger particles that are retained by the filter thereby causing a filtering film or layer on top of the filter bed.

Most dolphinaria use a combination of these systems and carefully used all these methods can give good results.
Let us finish this chapter realizing for ourselves why we do so much effort to obtain good water. First of all for the sake of the dolphins so we can offer them water pleasant to live in, that is: Free from bad odour and taste, not irritating to skin, eyes and mucuous membranes and free from possible pathogenic agents like bacteria, viruses and fungi. Secondly, for the sake of the audience and personnel: Water shall look attractive and be clear so that the animals can be observed all over the tank. This also facilitates the cleaning of the bottom and sides of the pool.

Chemistry of chlorination

Two types of chlorination plants are in general use: Either direct injection of gaseous chlorine which is selected in rather large installations from economical reasons or the addition of sodiumhypochlorite in solution. In the case with the elemental chlorine this will be dissolved in the water and undergo hydrolysis following the chemical equation (1)

$$Cl_2 + H_2O \rightleftarrows HOCl + H^+ + Cl^- \quad (1)$$

Chlorine will not be present in the water as Cl_2 unless the concentration is about 1000 ppm (parts per million or mg per litre) or the pH of the water is below 3 (for chlorine 'explosions' see later). Alternatively: Above pH 3 and in small chlorine concentrations the process will run completely to the right. The disinfectant part is the hypochlorous acid: HOCl, which will dissociate according to equation (2):

$$HOCl \rightleftarrows H^+ + OCl^- \quad (2)$$

If you add sodiumhypochlorite to the water it will dissociate after equation (3):

$$NaOCl + H_2O \rightleftarrows NaOH + HOCl \quad (3)$$

Again we find the hypochlorous acid which in turn will dissociate as in equation (2).

The use of gaseous chlorine will tend to lower the pH, while addition of sodiumhypochlorite will raise the pH. The relative distribution of the hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-) is pH dependent according to fig. 2. This relation is very important to notice since it is the hypochlorous acid which possesses the major disinfectant action, about a 100 times more effective than the OCl^-. To the poolkeeper this means that the efficiency of the chlorination depends on the pH. It is seen from fig. 2 that at pH around 7,5 there is an equal distribution of HOCl and OCl^-. At pH 7 about 75% will be present as HOCl and a much better efficiency is obtained. In practice this means that if you want to keep 1 ppm HOCl at pool pH 8 you need 4 ppm free chlorine (HOCl = 25% and OCl^- = 75%).

During chlorination the chlorine combines with ammonia and other nitrogenous compounds to form chloramines which in turn can also be disinfective but to a much lesser degree.

The formation of chloramines with ammonia nitrogen runs after the following equations (Fair et al. 1948):

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O \quad (4)$$

$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O \quad (5)$$

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O \quad (6)$$

The relative distribution of monochloramine NH_2Cl, dichloramine $NHCl_2$ and trichloramine NCl_3 is pH dependent. At relative high pH the monochloramine is dominant and at low pH — that is less than pH = 4 — the trichloramine is prevailing. In water with a pH adjusted to that of sea water, pH between 7,8-8,2, most chloramine will be in the form of monochloramine. The distribution of chloramines also depends on the ration of chlorine to ammonia nitrogen by weight.

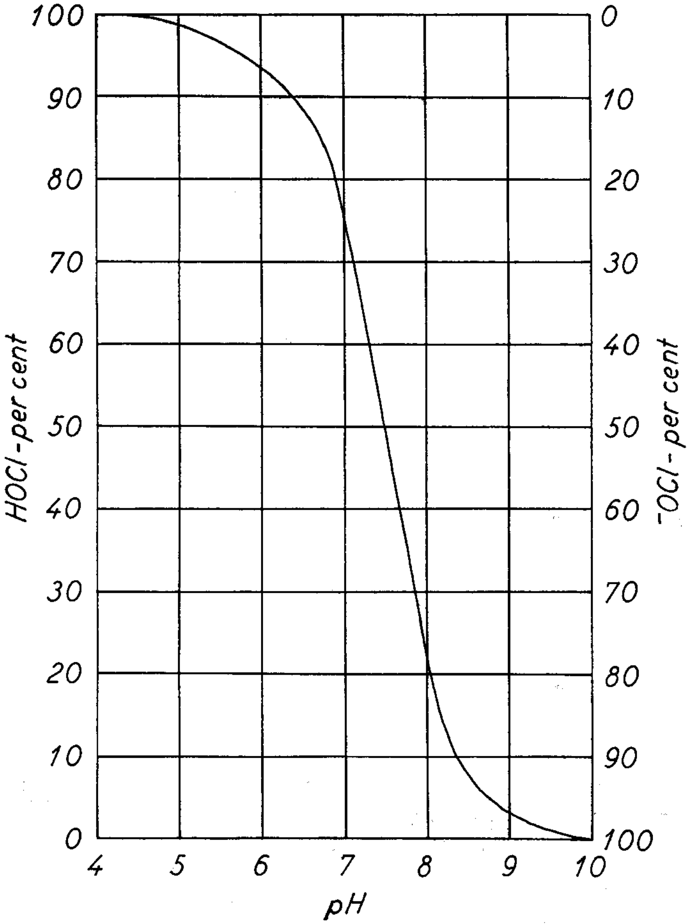

Fig. 2: The distribution of hydrochlorous acid and hypochlorite ion in relation to the pH of the water, see text. In all methods of determination both compounds together are expressed as free available chlorine.

If the ratio is less than 5 : 1 monochloramine will be almost 100% dominating. Between the ratios 5 : 1 and 10 : 1 the dichloramine is formed in still higher concentrations. At ratios more than 10 : 1 trichloramine may be formed.
Monochloramine is a relative poor disinfectant compared to the hypochlorous

acid — about 100 times less — and does not easily escape from the water during the aeration caused by the animals movements. Dichloramine is a better disinfectant than monochloramine but it disappears easier during agitation and gives off a disagreeable odour. Trichloramine has a nauseous and very disagreeable odour and acts very irritantly to the eye and should absolutely not be present in or around the pool.
The above mentioned considerations are all valid for the simple compounds between the hypochlorous acid and ammonia nitrogen; but chemical reactions occur also between hypochlorous acid and the numerous organic nitrogenous compounds that are present in the pool originating from urine, faeces and food left-overs. Mono-, di- and trichloramines (N-chloro-compounds) are also formed with these compounds after the reactions in equations 4 - 6 but the reactions occur much slower and the elimination of N_2 from the poolwater is therefore much retarded. Some of the organic N-chloro-compounds, specially those formed with creatinine — they are measured in the dichloramine fraction, see later — are extremely stable even in the presence of high concentrations of HOCl (White 1972).
The presence of both ammonia nitrogen and N-chlorocompounds in pool water causes the same problems:

1. They act as irritants to mucous membranes and give off disagreeable odour.

2. They consume chlorine which should be saved for the inactivation of pathogenic agents.

3. They are nutrients for bacteria and fungi.

In this chapter we have dealt with different chlorine compounds and we shall return to them in the next chapters, so let us summarize:

Free chlorine: Chlorine in form of hypochlorous acid, HOCl and the hypochlorite ion, OCl^-. Together they form the most effective Cl compound odourless, tasteless and non toxic even in high concentrations.

Combined chlorine: compounds of chlorine and nitrogen ammonia or organic nitrogenous compounds.

Total chlorine: free and combined chlorine measured together.

All the compounds are measured in terms of equivalent elemental chlorine (Cl_2) in ppm or mg per litre.

Methods of chlorination

1. *Breakpoint chlorination*

If chlorine is added to distilled water there will exist a linearity between the added amount of chlorine and the measured chlorine which will be present as HOCl and OCl^- or free chlorine, see fig 3 dotted line. If chlorine is added to water containing nitrogenous compounds this linearity does not hold and, moreover, there will be formed combined chlorine, see fig. 3 full drawn line. If chlorine is added in increasing amounts to water containing a fixed concentration of nitrogenous compounds you will measure a rising concentration of total chlorine almost exclusively consisting of combined chlorine until a certain moment, when the concentration of combined chlorine as monochloramine starts to decrease and monochloramine is replaced by dichloramine. At the dip of the curve free chlorine ($HOCl + OCl^-$) will start to appear: Breakpoint. After this, further addition of chlorine will give a rise in free chlorine proportional to the added amount of chlorine as in the first experiment with distilled water. Trichloramine may show up now as well with mono- and dichloramine at a minimum. Now the water contains both free and combined chlorine but free chlorine is prevailing.

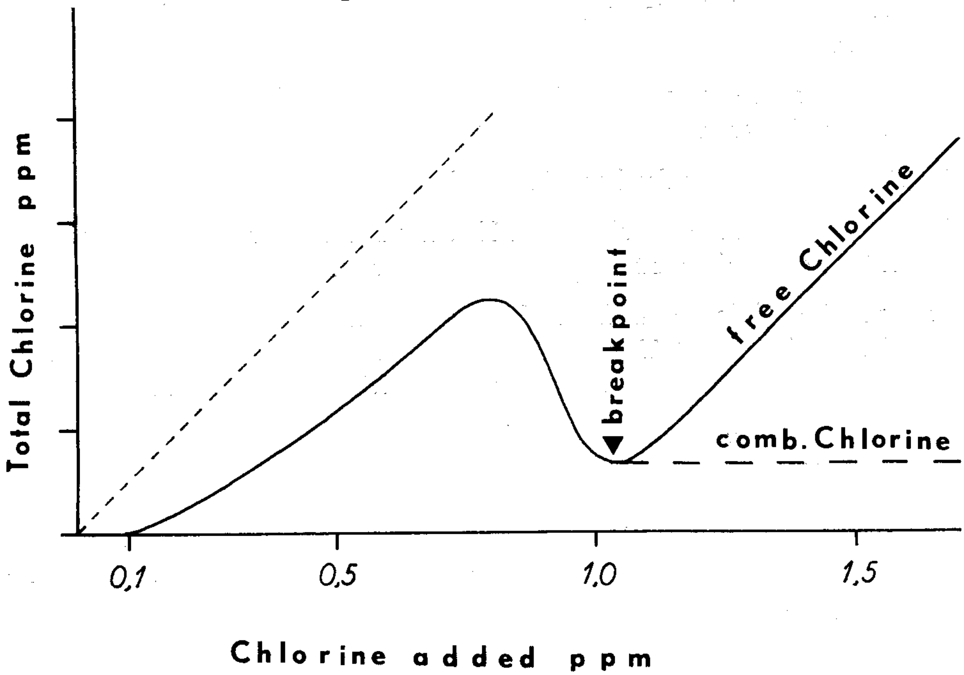

Fig. 3: Ideal residual chlorine curve, illustrating the principles of marginal and free residual chlorination, see text.

This is a drinking water situation developed during World War I. A certain amount of water of unknown quality that a soldier wished to drink was chlorinated above breakpoint and allowed for reaction. Hereafter it was dechlorinated and consumed in lack of other safe water sources.

In dolphinaria the content of nitrogenous compounds is most often so high and also changing from time to time that breakpoint chlorination is not easy to use. To reach the breakpoint it is often necessary to raise the concentration of free and combined chlorine to levels that can affect the animals seriously. Nothing is published on the tolerance of the bottle-nosed dolphin to high concentrations of combined and free chlorine. It has been reported (Dudok van Heel, personal communication) that the bottle-nosed dolphin can stand 20-30 ppm free chlorine as long as the chloramine concentration is lower than 2 ppm. This is also an experience from human swimming pools.

It should be noted here that breakpoint chlorination is very difficult to maintain. It is a description of the process of formation of free chlorine and N-chloro-compounds during addition of increasing amounts of chlorine to water containing a defined amount of nitrogenous compounds. However, it serves to make us understand what happens when chlorine is added to pool water. It has taught us that we reach a rather well defined situation when we keep well to the right of the breakpoint. If we let the chlorine concentrations slide back and forth through the breakpoint, there is a risk that the injurious di- and trichloramines are formed. Furthermore, when the water contains organic nitrogenous compounds — which is most often the case — the hump and the dip in fig. 3 are much less pronounced and therefore more difficult to determine.

2. *Marginal chlorination*

The principle of this method is that a certain 'safe' concentration of free chlorine is kept to assure the killing of pathogenic agents, almost without respect to the amount of combined chlorine.
It is generally agreed for human swimming pools that if a measurable content of free chlorine is present, e.g. at least 0,1 ppm, most bacteria are inactivated within a reasonable time. In dolphin pools minimum concentrations of 0,2 ppm are necessary combined with hyperchlorination (see below).
Referring again to fig. 3 the situation of the marginal chlorination is represented to the left of the breakpoint. The ration between free and combined chlorine is always contrary to the free residual chlorination — see overleaf — because the concentration of free chlorine is lower than the concentration of combined chlorine. This usually gives the water a bad smell and a greenish colour, and this is exactly the most common dolphinarium situation: the

keeper does not dare to pass the breakpoint because then he has to raise the combined chlorine concentrations to injurious levels or take the animals out out of the pool.

3. *Free residual chlorination*

By this method the keeper holds the chlorination process well to the right of the breakpoint — see fig. 3*. There will, always, in a dolphin pool be some combined chlorine present, but the ratios between free and combined chlorine can easily be kept about 2 : 1 or better 3 : 1. The crucial point of this type of chlorination is an exact differentiation between the free and combined chlorine. We shall return to this problem under the chlorine measurements. It is the authors opinion that this method is the most successful one.

Addition of chlorine

In a large dolphin installation with more than 100 m^3 water per animal (bottle-nosed dolphin) the administration of dissolved sodiumhypochlorite can be done safely enough using only a bucket several times during the day, as long as one does not aim at breakpoint chlorination. The expected fluctuations in chlorine concentration will be damped by the huge water volume. But if the water volume is smaller it is imperative to use dosage pumps that allow an exact administration of chlorine. Attention is drawn to the chapter on safe handling of chlorine.

Dechlorination

In some cases it is desirable to be able to lower the chlorine concentration, for instance after hyperchlorination or in case of erroneous dosing. Most often sodiumthiosulphate, $Na_2S_2O_3$ — 'hypo' or fixing salt — is used because it leaves harmless compounds in the water like sulphate and chlorine ions. To lower the concentration of free chlorine 1 ppm in 100 m^3 of water 0,5 kg crystalline fixing salt is required. Even better is the use of hydrogenperoxide as it does not give extra ions and does not effect the pH level in the pool or in the test tube.

The pH of the water

pH is defined a negative logarithm to the base 10 of the hydrogen concentration. A neutral solution has a pH of 7, acid or 'sour' solution has lower values — down to 1 — and alkaline solutions have higher values — up to 14. The pH of the water can be lowered by addition of hydrochloric acid and increased with the

* Editor's note: In daily usage this method is often called 'breakpoint chlorination'.

addition of dissolved sodium hydroxide. There has been much speculation about the best pH in a dolphin pool, because it can be seen from many viewpoints. It seems most natural to adjust the pool pH to that of sea water which is between 7,8 and 8,2 but for physiological reasons it should be kept close to 7,4 which is the pH of the body fluids in mammals. This physiological consideration does not carry much weight since we know that the animals are adapted to life in the sea. However, we have seen earlier that to obtain the best germicidal effect we should keep the pH relatively low so the hypochlorous acid is dominating in the free chlorine fraction.

There are few references to pool pH in the literature. The Talahassee rules and guide lines (1972) recommend 7,8 to 8,3 i.e. close to that of sea water and Ridgway recommends 7,4 to 7,8. Our experience with the harbour porpoise has shown a safe margin between 7,4 and 8,0.

It is the experience from human swimming pools that the pH should be raised with increased chlorine concentrations to avoid skin irritations. A rough guide for porpoise pools is:

pH 7,3-7,5 for free chlorine about 1,5-2,5 ppm with free residual chlorination.

pH 7,7-7,8 for free chlorine about 0,3 ppm with marginal chlorination.

In the case where liquid sodiumhypochlorite is used (about 15%) in chlorination the pH tends to raise. Therefore — as a rule of thumb — for every 50 L of hypochlorite it is necessary to add 1 litre (about 40%) of hydrochlorous acid.*

Precipitation with aluminium compounds

It was mentioned that one of the methods by which we could get rid of an accumulation of small particles and increasing colouration was by means of chemical precipitation.

N.B.: Chloramines cannot be moved away by precipitation.

Most often aluminiumsulphate $Al_2(SO_4)_3$, and sodiumaluminate, $NaAlO_2$, is used (Gewalt, 1969). Aluminiumhydroxide is formed in the water by hydrolysis in the presence of alkaline substances like calciumbicarbonate. The suspended particles which are all negatively charged come together in contact with the aluminium hydroxide flocs that can grow large enough to be withdrawn in the filter. Theoretically, the best effect is obtained if the flocculation is done in special deep tanks where the forming flocculants can settle and long time is allowed for the reaction. In practice, however, many dolphinaria apply aluminium continuously in amounts of e.g. 1 gram per m^3 per hour (Gewalt, 1969). The aluminiumhydroxide flocculations form a filtering film on top of the filterbed and thus aid filtering.

*N.B. They shall not be mixed in the same bucket, see safe handling of chlorine. A little less is required when aluminiumsulphate is used for flocculation.

The determination of chlorine

We have now learnt that it is important to know which of the many oxidizing chlorine compounds we have in the pool. Even in serious papers statements of chlorine concentrations like 0.1 ppm chlorine can be found without indicating whether it is free or combined chlorine. If one uses such statements it is necessary to name them precisely. In Europe there are essentially 2 methods in use for the field determination of chlorine.

The DPD method

This method is recommended over the orthotolidine flash method because it gives a clear distinction between the free and the combined chlorine and because it is not hazardous to the health. Diethyl — para — phenylene diamine, DPD (Palin 1957), reacts with free chlorine producing a red colour. Addition of small amounts of potassiumiodide immediately causes monochloramines to produce a red colour. Subsequent addition of potassiumiodide immediately causes monochloramines to produce a red colour. Subsequent addition of potassiumiodide in excess evokes a response from the dichloramines. The colours developed are matched against a standard colour disc in a comparator or in a Nessleriser stand with a standard light source. The range covered by the discs is between 0.02 - 10 mg Cl_2 per liter. For practical purpose in dolphin plants the ranges 0.1 - 4.0 ppm and 0 - 10ppm are recommended.

Orthotolidine flash

Orthotolidine is used in an acid solution and produces immediately in contact with the water sample a yellow colour indicating the content of free chlorine and successively it reacts with the combined chlorine. The yellow colour is matched with a calibrated colour disc. Since the reaction with free and combined chlorine is a continuous process it can be difficult to discern between them, especially at higher concentrations of combined chlorine. Cooling of the water sample and addition of sodium arsenite is recommended since it retards the reaction with the dichloramines (Standard Methods 1971). It has been shown that orthotolidine is carcinogenic, causing cancer of the urinary system. It is now forbidden to be used in the U.K. and ought to be abandonned in dolphin plants and private swimming pools.
There are several other methods (see Standard Methods for the Examination of Water and Waste Water 1971) but they are only for use in analytic laboratories since they require trained personnel and expensive equipment. All known methods are not very reliable for the measuring of chlorine in the low level concentration which exists in dolphin pools. Standard Methods (1971) indicate a relative standard deviation of about 30 per cent for most of the methods.

When determinating chlorine concentration with different methods you can very well find differences between them in an order of magnitude of about 2 or more. Furthermore, the sampling and transport of the water before the measurement is done, have a great influence and the analyst's routine is very important and must be carefully controlled. When using comparators a standard light source is necessary to obtain values of reasonably good reproducibility. The author has made an experiment on the importance of adding the reagent to the sample against adding the sample to the reagent in the testtube. In 18 successive measurements in a pool with rising values of free chlorine — during the day — it was found that adding the drop first in the testtube gave about 30 per cent higher values ranging from 20 to 50 per cent. Typical differences were e.g. 0.3 ppm and 0.1 ppm free chlorine. This indicates how difficult it is to obtain reproducible values and how careful you must be to discuss differences at these low level measurements. Another thing is that once a method has become routine rather constant values can be obtained but it is very wise now and then to have the actual chlorine concentration checked at an analytic laboratory.

The author also made a comparison between the orthotolidine flash and the DPD method using a LOVIBOND 1000 comparator. The values for free chlorine were sufficiently corresponding but for combined chlorine the DPD method gave values systematically about 2 times greater than the orthotolidine flash method. The same relation has been shown between the orthotolidine-arsenite and the ferrous DPD methods (see Standard Methods 1971) performed in an analytic laboratory with trained personnel.

Other factors that act upon the accuracy of the chlorine determination are: the unequal distribution of chlorine in the pools which is a function of the method of chlorine addition and of the water miscibility. If water samples are transported, the influence of temperature and ultraviolet radiation can be essential. Nitrites if present in the water can produce the same yellow colour as with the orthotolidine and oxidised manganese can produce a red colour with the DPD. Manufacturers' leaflet on the methods indicates methods by which these sources of error can be avoided.

Filter systems

In the choice of filter systems economical considerations are often deciding. The sandfilters usually take up much space but they are the most easy to maintain. In contrast to these the diatomaceous earth filter has small outer dimensions and large internal surface. But it is more troublesome to maintain and no less expensive to install.

Sandfilters

The oldest type is the open sand filter where the water is sucked through or by gravity runs through the filter bed. This consists of from the bottom upwards, a water space under a sieve board carrying layers of gravel and sand which decrease in diameters towards the top. This filter type permits only a slow filter rate e.g. 5 to 10 m^3/hour/m^2 surface. If the rate becomes higher the filter bed cannot carry the pressure difference and the water will run through the filter in narrow funnels almost unfiltered. The slow rate gives a fine filtering effect. To the disadvantage of these filters is that they take up enormous space. E.g. for a dolphin plant of 300 m^3 the filter surface for a filter rate of 5 m^3/h./m^2 and a turnover of 2 hours will be 30 m^2. To ensure an effective backwashing the surface of each filter should not exceed, say 10 m^2. Injection of air at the bottom of the filter saves water (which is often taken from the pool to ensure sufficient flow) and makes the backwash more effective.

A modern sand filter type is the High-rate filter where filter gravel of uniform size is placed on a bed of coarser grain in a closed filter tank and the water is pressed through the gravel under high pressure and a very high flow, e.g. 50 m^3/h./m^2. This type is much in use because it is effective, easy to maintain, and it saves space. In order to protect the pump against course material a hairstrainer is built in the system in front of the pump. This strainer makes instant inspection of this material possible, e.g. skin pieces, faecal material, vomited foodstuffs and alien objects. This inspection can be important for the diagnosis of abnormal conditions among the animals.

On top of the filter can be placed an active charcoal layer which can make the filter more effective. But it retains also added chlorine, looses its activity soon and bacteria and dirt in this layer can be difficult to wash out. The flocculation agents mentioned earlier are to be favoured in this respect and by using them the High-rate filter equals the diatomaceous earth filter.

Diatomaceous earth filter

This type consists of a tank with a row of hollow plates with holes to the outer surface. The holes are covered by a fine-meshed nylon cloth. The tank is filled with diatomaceous earth and when water is flowing from inlet to outlet, the diatoms will aggregate on the filtering cloth and form a filter layer. This type retains particles a little smaller than the sand filter, e.g. down to 0.1 mm. At each backwash the dirt and the diatoms will disappear in the sewer. With many filter plates a great filter area can be obtained in comparison to the filter tank surface. The water can either be pressed through the filter cloth in closed tanks or sucked through in open tanks. A disadvantage of the systems is the steady consumption of expensive (in Europe) diatomaceous earth and the wearing of the filter cloths which from time to time have to be renewed.

With both sand and diatomaceous filters it should be remembered that the water that goes through the filter immediately after the backwashing is not filtered very well because it takes some time for the filter material to settle and thus become effective. The first water after backwashing ought to be discarded into the sewer to avoid contamination of the pool water.

The clarity of the water

Pure water as in perfectly driven swimming pools is blue and you can easily look through it at a distance of say 25 meters, that is: see separations between the tiles of the walls. When judging the purity of the pool water it is important to have underwater windows permitting inspection of the water through the longest distance of the pool. When looking at the water from above you look from the surface to the bottom and you are not able to see even rather large particles suspended in the water. Even with sunlight or light from spotlights over the tank, forming light patterns on the bottom through the uneven surface, suspended particles do not show up.

The faeces of diarrhoeic dolphins contain a green dye — biliverdine (in normal faeces this is oxidized to the brown compound, stercobiline) — and this dye can turn the water green. It is interesting to note that obviously good swimming pool water with a concentration of free and combined chlorine of 1.0 and 4.0 respectively, can be bright blue in spite of the high concentration of combined chlorine. The colour of the water is not only a matter of combined chlorine content, but also of ammonia nitrogen.

Water circulation in the pools

There has been much speculation on how to design the optimum circulatory system and still new systems appear indicating that the best one has not yet been constructed. The idea is that there shall be an effective mixing of the inflow with the pool water to avoid the development of dead water volumes where growth of bacteria can occur. Secondly a mechanical cleaning of the water by a high turnover, e.g. 1 to 2 hours and an effective filtering system are imperative for breakpoint chlorination. In order to avoid dead water it has been suggested that some of the inflow be injected at different sites over the bottom or to let part of the outlet water go back unfiltered to the pool. Also the provision of several outlets and inlets can give a better mixing of the water. The contours of the pool and bottom shape are factors to remember when circulation — and cleaning — are to be considered.

The turnover of the whole water body is recommended to take place each 1 to 2 hours (Ridgway 1972). This is a theoretical figure but the more effective the mixing of the water is, the more realistic the figure becomes. Ridgway (1972) has recommended the following formula for a good minimum turnover rate:

$$GPM = 4 \times \frac{TC}{1000} + (0.5 + \frac{TC}{1000} \times \frac{AW}{100})$$

where TC = tank capacity in gallons
AW = the total animal weight in kg
GPM = gallons per minute

(1 American gallon = 3.785 liters, almost 4 liters).

In large plants it is practical to have separate water systems for each pool and, of course, the important quarantine basin — very often failing in dolphinaria — shall have its own system.

Toxic considerations

Chlorine

Chlorine is dangerous both to humans and animals in high concentrations. In air man can detect easily elemental chlorine in concentrations of 3 - 5 ppm. The gaseous chlorine elemental or in combined compounds acts as irritants to skin, mucous membranes and eyes and higher concentrations cause suffocation. In solutions combined chlorine causes burnings of eyes and skin. For the bottle-nosed dolphin an upper safety limit is given (Ridgway 1972) of 0.4 ppm, most probably free chlorine, since much higher values for combined chlorine are found in most dolphinaria. It is impossible to state a maximum limit for the free chlorine ($HOCl + OCl^-$) alone unless the ammonia content and the combined chlorine values are taken into consideration (see chapter on chlorination). HOCl is odourless and tasteless and not toxic, even in high concentrations (50 ppm) and the most ideal disinfectant. A slight skin reaction from chlorine can be difficult to distinguish from the ordinary and rapid skin peeling among dolphins in captivity but deep maceration of the skin with formation of deep grooves and the loosing of large parts of thick skin pieces as seen by the author due to accidental liberation of elemental chlorine in the water, is a well defined symptom.
In this context it shall be mentioned that a recommended relation between free and combined chlorine in public swimming pools is 2 : 1 or better 3 : 1. Very often this is upside down as it is in public swimming pools. The keepers try to raise the values of free chlorine but dare not pass the breakpoint

because they then exceed the safety limits. If they do so they will suddenly measure high levels of free chlorine if not compensated for by lowering the chlorine dosage. These high concentrations are sometimes erroneously described as chlorine explosions.
Real chlorine explosions can only happen when chlorine is gaseous but it is a general expression among dolphin keepers describing the liberation of elemental chlorine in the water. This can happen in outdoor pools exposed to heavy sun radiation under the influence of ultraviolet radiation, when chlorine and acid are mixed, if chlorine in high concentrations comes into contact with iron or if the pH value becomes lower than 5.
Very little is known of the effect on the intestinal flora from the chlorinated environment. Chlorine concentrations of 0.1 ppm or more occur in drinking water in many countries as a bacteriostatic agent. It is believed that the chlorine is not injurious to human health since it becomes inactivated when coming into contact with organic matters in the stomach and intestines. Apart from this it has not yet been proved beyond doubt whether dolphins regularly drink water or not, but no doubt some water will pass to the stomach together with the food.

Aluminium

We have no records in the literature on the toxicity of aluminium to dolphins. In human swimming baths 0,1 mg per litre is known to irritate eyes and 0,5 mg per litre is acutely irritating. Aluminium acts astringent on mucous membrane surfaces. When using aluminium as a flocculant it should not pass through the filter. This can happen accidentally and there can thus be a slow accumulation of it in the pool water, dependent on how much make-up water is added.

Copper

The upper limit of copper concentration is stated by the Talahassee rules and guidelines (1971) as 1,0 mg per litre. It is added especially to outdoor pools as an algicide as coppersulphate, and acts as such in higher concentrations as irritants to the skin. Fitzgerald (1959) has reported that the use of chlorine as an algicide is in most cases better since the coppersulphate acts rather selectively to various species of algae.

Salt

The salinity in the seas in which the bottle-nosed dolphin lives is between 20 and 35‰ NaCl. Although salinities of 14-20‰ have been used it is generally accepted now that 20‰ should be the minimum with a preference for 25-

30‰ for the bottle-nosed dolphin. Corneal opacities can develop at lower salinity together with a maceration of the skin due to osmotic disturbances.
Harbour porpoises which are known to live in estuarine waters have been exposed to fresh water in our laboratory. Two animals were transferred from salinity of about 20‰ to fresh water and in one week they both got their skin macerated to a degree that it could be rolled off in small granules.

Acknowledgements

The author wants to express his gratitude to Eng. H. C. Schouv Hansen, department of public swimming baths, Odense, Denmark, for many valuable discussions and suggestions and to dr. W. H. Dudok van Heel, Dolfinarium Harderwijk, Holland, who placed his many years of experience at my disposal for this paper.

REFERENCES

DUDOK VAN HEEL, W. H., 1972: Raised levels of mercury and clorinated hydrocarbons in newly captured *Tursiops truncatus* (Mont.) from Florida waters. Aquatic Mammals, Vol. 1 no. 2, p. 24-36.

FAIR, G. M., MORRIS, J. C., SHANG, S. L., WEIL, I. & P. BURDEN, 1948: The Behaviour of Chlorine as a Water Disinfectant. J. Amer. Water Works Assoc. 40, p. 1051-61.

FITZGERALD, G. P., 1959: Bactericidal and Algicidal Properties of some Algicides for Swimming Pools. Applied Microbiol., 7, p. 205-11.

FUCHS, 1962: Chemiker Zeitung, 86: p. 76-83.

GEWALT, W., 1969: Erste Duisburger Delphinerfahrungen mit Tursiops truncatus. Der Zool. Garten. 36: 6, p. 268-311.

HAAG-RÜCK, 1971: Archiv des Badewesens 24: 7, p. 371-77.

MARINE MAMMALS CAPTURE, Maintenance and Shipping Procedures. Interdepartemental Standards of the Department of Natural Resources. Fla. USA 1970.

PALIN, A. T., 1957: The Determination of Free and Combined Chlorine in Water by the Use of Diethyl-p-phenylene Diamine. J. Amer. Water Works Assoc. 49, p. 873-78.

RIDGWAY, S. H., 1972: Mammals of the Sea. C. C. Thomas, Springfield, Illinois. USA.

STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 13. ed. Amer. Public Health Assoc. Wash. USA 1971.

WALLIS, A. P. L., 1972: The maintenance of satisfactory water conditions in dolphinaria, Aquatic Mammals, Vol. 1, no. 3, p. 19-25.

WHITE, G. C., 1972: Handbook of Chlorination. Van Nostrand Reinhold Company, New York, Chapter 8, p. 466-526.