AQS415 PRINCIPLES OF AQUACULTURE ENGINEERING

Week 5. Water quality for aquaculture

The following physico-chemical changes in the aquatic environment are those most frequently recorded as the primary factors in fish culture installations.

Water temperature

Fish are poikilothermic animals, that is, their body temperature is the same as, or 0.5 to 1°C above or below, the temperature of the water in which they live. The metabolic rate of fish is closely correlated to the water temperature: the higher the water temperature (i.e. the closer to the optimum values within the normal range), the greater the metabolism. This generalisation applies particularly to warm-water fish. Cold-water fish, e.g. salmonids, whitefish, or burbot, have a different type of metabolism: their metabolic rate can continue at comparatively low temperatures, whereas at high water temperatures, usually above 20°C, they become less active and consume less food. Water temperature also has a great influence on the initiation and course of a number of fish diseases. The immune system of the majority of fish species has an optimum performance at water temperatures of about 15°C. In their natural environment, fish can easily tolerate the seasonal changes in temperature, e.g. a decrease to 0°C in winter and increase to 20–30°C (depending on species) in summer under Central European conditions. However, these changes should not be abrupt; temperature shock occurs if the fish are put into a new environment where the temperature is 12°C colder or warmer (8°C in the case of salmonids) than the original water. Under these conditions fish may die, showing symptoms of paralysis of the respiratory and cardiac muscles. With young fry, problems may arise even where the difference in temperature is as low as 1.5–3°C. If fish are fed and then abruptly transferred to water colder by 8°C or more, their digestive processes will slow down or stop. The food will remain undigested or half-digested in the digestive tract and the gases produced can cause the fish to become bloated, lose balance, and finally die. If carp are given a high-nitrogen feed (e.g. natural food or high-protein pellets), abrupt transfer to much colder water will considerably increase the level of ammonia nitrogen in the blood serum because the decrease in metabolic rate reduces the diffusion of ammonia from the gills.

This can lead to ammonia autointoxication and death. Considerable progress has been made recently in warm water fish culture. Techniques for water temperature control enables optimal condition to be maintained, so that the fish can fully utilize their growth potential to achieve maximum weight gains. 3.1.2 Water pH The optimal pH range for fish is from 6.5 to 8.5. Alkaline pH values above 9.2 and acidity below 4.8 can damage and kill salmonids (e.g. brown and rainbow trout); and pH values above 10.8 and below 5.0 may be rapidly fatal to cyprinids (especially carp and tench). Thus salmonids, in comparison with cyprinids, are more vulnerable to high pH and more resistant to low pH. The American char is especially resistant to acid waters and can tolerate pH levels as low as 4.5–5.0. Low water pH most frequently occurs during the spring, especially when acidified snow melts, and in water draining peat bogs. High alkaline pH can occur in eutrophic reservoirs (ponds) where the green plants (the blue-green algae, green algae and higher aquatic plants) take up considerable amounts of CO2 during the day for intensive photosynthetic activity. This affects the buffering capacity of the water and the pH can rise to 9.0–10.0 or even higher if bicarbonate is adsorbed from waters of medium alkalinity. Water pH can also be changed when mineral acids and hydroxides, or other acidic or alkaline substances, are discharged or leach into water courses, ponds or lakes. As a defence against the effect of a low or high water pH, fish can produce an increased amount of mucus on the skin and on the inner side of the gill covers. Extremely high or low pH values cause damage to fish tissues, especially the gills, and haemorrhages may occur in the gills and on the lower part of the body. Excess amounts of mucus, often containing blood, can be seen in post mortem examination of the skin and gills. The mucus is dull-coloured and watery. Water pH also has a significant influence on the toxic action of a number of other substances (e.g. ammonia, hydrogen sulphide, cyanides, and heavy metals) on fish. 3.1.3 Dissolved oxygen Oxygen diffuses into the water from the air especially where the surface is turbulent and also from the photosynthesis of aquatic plants. On the other hand, oxygen is removed by the aerobic degradation of organic substances by bacteria and by the respiration of all the organisms present in the water, as mentioned earlier. The concentration of oxygen dissolved in water can be expressed as mg per litre or as percentage of air saturation value. Water temperature, atmospheric pressure and contents of salts dissolved in water have to be taken into account when the values in mg per litre are converted to % saturation or vice versa. Different fish species have different requirements for the concentration of oxygen dissolved in water. Salmonids have the more demanding requirements for oxygen in the water; their optimum concentration is 8–10 mg per litre, and if the level declines below 3 mg per litre they begin to show signs of suffocation. Cyprinids are less demanding; they can thrive in water containing 6–8 mg per litre and show signs of suffocation only, when the oxygen concentration falls to 1.5–2.0 mg per litre. The oxygen requirements of fish also depend on a number of other factors, including the temperature, pH, and CO_2 level of the water, and the metabolic rate of the fish. The major criteria for the oxygen requirement of fish include temperature, and the average individual weight and the total weight of fish per unit volume of water. Oxygen requirements increase at a higher temperature (e.g. an increase in water temperature from 10 to 20°C at least doubles the oxygen demand); a higher total weight of fish per unit volume of water can lead to increased activity and thus increased respiration as a result of overcrowding.

Oxygen requirements per unit weight of fish significantly decline with increasing individual weight. In carp this reduction may be expressed by the following ratios: yearling = 1, two-year-old carp = 0.5–0.7, marketable carp = 0.3–0.4.

Significant differences in oxygen demand are also found for different species. Using a coefficient of 1 to express the oxygen requirement of common carp, the comparative values for some other species are as follows: trout 2.83, peled 2.20, pike perch 1.76, roach 1.51, sturgeon 1.50, perch 1.46, bream 1.41, pike 1.10, eel 0.83, and tench 0.83. As stated earlier, the factor most frequently responsible for a significant reduction in the oxygen concentration of the water (oxygen deficiency1) is pollution by biodegradable organic substances (including waste waters from agriculture, the food industry, and public sewage). These substances are decomposed by bacteria which use oxygen from the water for this process. A few chemicals may be oxidized in the absence of bacteria. The concentration of organic substances in water in terms of their capacity for taking oxygen from the water can be measured by means of the chemical oxygen demand (COD, which represents a theoretical maximum) and the biochemical oxygen demand within five days (BOD_5, which represents the potential for bacterial degradation). The upper limit of COD, as determined by the Kubela method, for the optimal range for cyprinids in pond or river waters, is 20–30 mg O_2 per litre and the corresponding BOD_5 limit for cyprinids is 8–15 mg O_2 per litre, depending on the intensity of the culture and the rates of reaeration. For salmonids the corresponding levels are up to 10 mg O_2 per litre for COD and up to 5 mg O_2 per litre for BOD. In winter, fish are commonly killed by suffocation in polluted storage ponds and in summer this often happens in polluted water courses with high temperatures and low flow rates. In severely eutrophicated ponds, oxygen deficiency often occurs during the summer early in morning as a result of the night time oxygen consumption by bacteria for the decomposition of organic substances and the respiration of aquatic plants. In heavily fertilized ponds (e.g. those used for the treatment of sewage) with a constant inflow of degradable organic substances, oxygen deficiency can also be caused by an excessive development of zooplankton; the zooplankton itself requires oxygen for respiration and, in addition, its feeding pressure reduces the phytoplankton population which produces oxygen during the day.

Even in ponds where the oxygen levels have been satisfactory during the summer, when plant growth was vigorous, severe oxygen deficiencies can occur in the autumn when the plants begin to die and decompose. This deficiency can be more pronounced if the sky is heavily overcast during the day, so that the limited oxygen production by photosynthesis is further reduced. In these cases, the maximum oxygen deficiency occurs just before daybreak. In summary, the oxygen levels in water depend on the balance between the inputs from the air and plants, and the consumption by all forms of life. Inputs from the air depend on the turbulence of the air-water interface, and the oxygen deficiency of the water. Inputs from plants depend on photosynthetic activity which increases with temperature and sunlight; excess oxygen can be lost to the atmosphere. Oxygen consumption depends on the respiration of aquatic organisms, including plants, and the aerobic decomposition of organic material by bacteria; these rates also increase with temperature. This balance needs to be clearly understood; a satisfactory oxygen level recorded during the day is no guarantee that the levels will be maintained during the night. Moderate levels recorded in calm eutrophic waters on a warm, sunny afternoon will almost always indicate that severe oxygen deficiencies will occur during the night. Also, lower than expected daytime pH values due to high levels of CO_2 may indicate high levels of bacterial respiration which could lead to low night-time oxygen levels. Oxygen deficiency causes asphyxiation and fish will die, depending on the oxygen requirements of the species and to a lesser extent on their rate of adaptation. Fish exposed to oxygen deficient water do not take food, collect near the water surface, gasp for air (cyprinids), gather at the inflow to ponds where the oxygen levels are higher, become torpid, fail to react to irritation, lose their ability to escape capture and ultimately die. The major pathologico-anatomic changes include a very pale skin colour, congestion of the cyanotic blood in the gills, adherence of the gill lamellae, and small haemorrhages in the front of the ocular cavity and in the skin of the gill covers. In the majority of predatory fishes the mouth gapes spasmodically and the operculum over the gills remains loosely open. Remedial action is to either reduce the input of degradable material, or to aerate the water. The latter is usually the best option; aeration can be with air or oxygen pumps, or by spraying the water into the air in the form of a fountain, or by increasing the input of aerated water. It must be remembered that these remedial actions are most important at night when the oxygen deficiency is likely to be at its greatest. Damage caused to fish by too much oxygen dissolved in water is seldom encountered. However, it may happen, for example, when fish are transported in polythene bags with an oxygen-filled air space. The critical oxygen level of water is 250 to 300% of the air saturation value; fish may be injured at higher values. The gills of such affected fish have a conspicous light red colour and the ends of the gill lamellae fray. When such fish are used for stocking waters they may suffer from secondary fungus infections and some of them may die. It is possible that fish adapted to such high oxygen levels need to be progressively acclimatized to more normal concentrations. The condition described here should not be confused with the supersaturation of water with dissolved gas, which can cause gas bubble disease.

Supersaturation with dissolved gas Supersaturation with dissolved gas occurs when the pressure of the dissolved gas exceeds the atmospheric pressure. It occurs when water is equilibrated with air under pressure, e.g. at the bottom of a lake or reservoir, in ground water, or if air is drawn into a centrifugal water pump. It can also occur if cold air-equilibrated water is warmed up without re-equilibration to the higher temperature. A bottle containing such water will show either minute bubbles forming as a cloudy suspension which will clear from the bottom upwards, or larger bubbles forming on the glass wall. This is analogous to that seen in an opened bottle of carbonated drinking water. If fish are exposed (at a lower atmospheric pressure) to such water, their blood equilibrates with the excess pressure in the water. Bubbles form in the blood and these can block the capillaries; in sub-acute cases the dorsal and caudal fin can be affected, and bubbles may be visible between the fin rays. The epidermal tissue distal to the occlusions then becomes necrotic and cases are known where the dorsal fins of trout have become completely eroded. In severe cases, death occurs rapidly as a result of blockage of the major arteries, and large bubbles are clearly seen between the rays of all the fins. A similar effect of gas bubbles forming in the blood can be experienced by deep-sea divers when they return to the surface. The remedy is either to remove the fish to normally equilibrated water or to provide vigorous aeration to strip out the excess gas. 3.1.5 Ammonia 3.1.5.1 Factors associated with ammonia toxicity Ammonia pollution of water courses, ponds and lakes may be of organic origin (domestic sewage, agricultural wastes, or the reduction of nitrates and nitrites by bacteria in anoxic waters) or of inorganic origin (industrial effluents from gas works, coking plants and power generator stations). In water or in biological fluids, ammonia is present in a molecular (nondissociated) form (NH3) and in the form of ammonia ion (dissociated) (NH4 +). The ratio between these two forms depends on the pH and temperature of the water (Table 1). The cell walls of organisms are comparatively impermeable to the ammonia ion (NH4 +), but molecular ammonia (NH3) can readily diffuse across the tissue barriers where a concentration gradient exists, and is therefore the potentially toxic form to fish. Also, under normal conditions there is an acid-base balance at the water-tissue interface. If this balance is altered, the side on which the pH is lower will attract additional molecular ammonia. This explains how molecular ammonia passes from water through the epithelium of the gills to the blood and also how it passes from the blood to the tissues. Ammonia has a particular toxic effect on the brain; this is why nervous symptoms are so pronounced in cases of ammonia toxicity to fish. Water quality monitoring of water courses, lakes and fish culture facilities includes the measurement of total ammonia concentrations. Nitrites and nitrates Nitrites as a rule are found together with nitrates and ammonia nitrogen in surface waters but their concentrations are usually low because of their instability. They are readily oxidized to nitrate or reduced to ammonia, both chemically and biochemically by bacteria. Nitrates are the final product of the aerobic decomposition of organic nitrogen compounds. They are present in low concentrations in all surface waters. There is almost no nitrate retention in soil, so it is readily leached to watercourses, ponds and lakes. The main sources of nitrate pollution of surface waters is the use of nitrogenous fertilizers and manures on arable land leading to diffuse inputs, and the discharge of sewage effluents from treatment works. Nitrite can be associated with ammonia concentrations in the water. In normal aerobic conditions, ammonia is oxidized to nitrite and then to nitrate by two separate bacterial actions. If the second stage of oxidation is inhibited by bactericidal chemicals in the water, nitrite concentrations will increase. This may be important in small ponds or aquaria where water is recirculated through a purification filter; the ammonia-oxidizing bacteria need to become established for the filter to function, and they may be affected by the use of antibiotics to control fish diseases. The toxic action of nitrite on fish is incompletely known; it depends on a number of internal and external factors (such as fish species and age, and general water quality). The importance and role of these factors have been frequently studied and reviewed. Different authors often come to contradictory conclusions, and usually fail to offer a definitive explanation of either the mechanism of nitrite toxic action on fish or the modifying effects of different environmental factors. It is now clear that nitrite ions are taken up into the fish by the chloride cells of the gills. In the blood, nitrites become bound to haemoglobin, giving rise to methaemoglobin: this then reduces the oxygen transporting capacity of the blood. The increase in the amount of methaemoglobin can be seen as a brown colour of the blood and gills. If the amount of methaemoglobin in the blood does not exceed 50% of the total haemoglobin, the fish usually survive. If the fish have more methaemoglobin in their blood (70–80%) they become torpid, and with a further increase in the methaemoglobin level they lose their orientation and are unable to react to stimuli. Nevertheless, the fish may still be able to survive because the erythrocytes in their blood contain the enzyme reductase which can convert methaemoglobin to haemoglobin. This process can return the haemoglobin to its normal level within 24–48 hours, if the fish are put into nitrite-free water.