Water quality and
Water quality Management in Aquaculture

Aquaculture can be defined as the high-density production of fish, shellfish and plant forms in a controlled environment. Stocking rates for high-density aquaculture are typically thousand fold greater than wild environments. Modern fish culturists employ both open and close systems to raise fish. Open systems, such as, the raceways (used in hatcheries of both finfish and shellfish and also in eel, trout culture) are characterized by rapid turnover of water. Closed systems are commonplace in pond culture of carps, catfishes, tilapia, sea bass, prawn and shrimp among others. Closed aquaculture systems do not have rapid turnover of water, but do not have a high surface to volume ratio facilitating exchange of gases, nutrients, energy etc. with the surroundings. Such closed system, intensified, high-density aquaculture forms the basis of concern.

The different forms of high density, intensive aquaculture is quite similar because they all obey the same set of physical and chemical principles. These principles compose the subject of water chemistry and its net result i.e. the water quality. Poor water chemistry leads to deteriorate water quality, which causes stress to the organisms being raised. Efficient feed conversion, growth and marketability of the final product cannot occur unless the pond system is balanced or in harmony with nature. Therefore the overriding concern of the fish culturist is to maintain, 'balance' or 'equilibrium conditions' with respect to water chemistry and its natural consequence, good water quality.

Water quality for aquaculturists refers to the quality of water that enables successful propagation of the desired organisms. The required water quality is determined by the specific organisms to be cultured and has many components that are interwoven. Sometimes a component can be dealt with separately, but because of the complex interaction between components, the composition of the total array must be addressed. Growth and survival, which together determine the ultimate yield, are influenced by a number of ecological parameters and managerial practices. High stocking density of fish or crustaceans in ponds usually exacerbates problems with water quality and sediment deterioration.

Wastes generated by aquaculture activity (faeces and unconsumed feed) first settle in the bottom, as a consequence of organic waste and metabolites of degraded organic matter is accumulated in sediment and water. Part of the waste is flushed out of the ponds immediately or late after the organic matter has been degraded.

Culture of penaeids has become intensified since 1986. In an intensive system of *Penaeus monodon* culture salinity, pH and dissolved oxygen were the main parameters, which demonstrated fluctuations of 19.5-27.5 ‰, 7.4-8.2 and 4.66-8.25 mg/l respectively. In addition, ammonia-N (un-ionized plus ionized ammonia as nitrogen) increased exponentially with culture period, and jumped to 6.5 mg/l after 75 days of cultivation.

Low dissolved oxygen level is the major limiting water quality parameter in aquaculture systems. A critically low dissolved oxygen level occurs in ponds particularly when algal blooms die-off and subsequent decomposition of algal blooms and can cause stress or mortality of prawns in ponds. Chronically low dissolved oxygen levels can reduce growth, feeding and moulting frequency.

Another major consequence of aquaculture production is a high degree of variability in the concentration of dissolved nitrates, nitrites and ammonia. High feeding rates observed in prawn farms lead to eutrophic conditions characterised by substantial phytoplankton blooms. These blooms ultimately senesce and cause rapid increasing in ammonia levels in the ponds. The environmental conditions that create high ammonia concentrations may also cause increases in nitrite concentration. Both ammonia and nitrite can be directly toxic to culture organisms or can induce to sublethal stress in culture populations that results in lowered resistance to diseases.

Ammonia accumulates in culture systems following microbial decomposition of organic material and with some fertilization practices. Microbial decomposition leads to low oxygen concentrations. Low dissolved oxygen concentration increases the toxicity of ammonia to culture organisms. In an aqueous ammonia solution unionized ammonia exists in equilibrium with ionized ammonia and hydroxide ions. The unionized form is usually toxic as it has high lipid solubility and it is able to diffuse quite readily across the cell membrane. Ammonia is utilized as energy source by nitrifying bacteria (*Nitrasomonas* and *Nitrobactor*) and oxidised it to nitrite and nitrate.

The production of brackishwater shrimps, which showed a strong increase in the 70's and 80's, showed a declining trend during 90’s in most parts of the world. In general the decrease in shrimp production of aquaculture is attributed to over intensification, leading to the deterioration of the surrounding environment and of pond water and pond sediment quality. Stress reduced shrimps' resistance to pathogenic diseases, resulting in mass mortality. Development of aquaculture activities at a particular site cannot be carried out only by considering planned facilities and the quality of water on the site at its origin but also on the aspects of water quality management.

There is a strong relationship between the quality of the water in the pond and that in the water-surrounding environment. Degradation of surrounding water quality will be faster unless proper water quality management techniques are not implemented in the ever-increasing aquaculture system.

Aquaculture pond dynamics

Aquaculture ponds are a living dynamic systems they exhibits continuous and constant fluctuations. The pond undergoes a vast collection of both chemical reactions and physical changes. Exchange of atmospheric gases including Oxygen (O_2), nitrogen (N_2) and Carbon dioxide (CO_2) with the pond water are vital to the process of fish metabolism and plant photosynthesis. Inorganic substances (minerals) dissolve from the pond walls and bottom while precipitation of dissolved minerals occurs. Physicals exchanges between the pond its surroundings include absorption of sunlight (radiant energy) to fuel photosynthesis and supply oxygen with in the pond, heat exchange and volume changes caused by evaporation and precipitation (rain). Changes in the volume of a pond are very important as they affect the concentration of dissolved substances and correspondingly requirements for treatment. Hence, the pond dynamics not only depend on its own characters and conditions but also on the surrounding atmospheric weather conditions. Good production from aquaculture ponds can be achieved when the pond and surroundings make chemical and physical exchanges at a steady state. When all of the processes balance, a state of equilibrium is achieved. Pond equilibrium is the optimum set of conditions for aquaculture, a state completely in harmony with nature.

Water chemistry

A guiding principle of aquaculture is that water quality and hence efficient production are a direct consequence of good water chemistry. Water may be considered as a 'binder' or 'matrix' in which the dissolved gases, inorganic substances (minerals), as well as organic matter prevails. In addition to dissolved substance, the water matrix gives support to microorganisms, plant and animal life forms and provides a medium for chemical exchange among these populations. However, water is itself relatively chemically inert, physically water has a high heat capacity (holds heat efficiently), is relatively 'polar' affording it the ability to act as an excellent solvent and is also quite dense. Its boiling point is quite high compared to similar molecules and its freezing point quite low. Therefore, water exists as a liquid over a rather broad range of temperature making it a most suitable medium for the support of life forms.

The maintenance of good water quality is essential for both survival and optimum growth of culture organisms. The levels of metabolites in pond water that can have an adverse effect on growth are generally an order of magnitude lower than those tolerated by fishes/prawns/shrimps for survival. Good water quality is characterized by adequate oxygen and limited levels of metabolites. The culture organisms, algae and microorganisms such as bacteria produce metabolites in a pond. The major source of nutrients in aquaculture is the feed. Because large quantities of feed are loaded in ponds, excess feed, fecal matter and other metabolites become available in large quantities for the growth of algae and microorganisms.

At one point, the increase in population of algae and microorganisms is exponential. This usually occurs during the second half of the culture period because of available nutrients. About 30% of the total feed consumption is loaded into the pond during the third quarter of the culture period and about 50% is loaded during the last quarter. The algae and microbial population increases until a factor required for growth becomes limiting, after which a sudden decrease in the population can occur. This is referred to as a "collapse" or a "die-off". The sudden increase and decrease in algal and microbial population can cause drastic changes in water quality parameters, which may affect growth.

By realizing the overriding significance of water chemistry, it is important to have a firm grasp of some basic concepts. Like:

Temperature

Aquaculture organisms are cold-blooded animals. They can modify their body temperature to the environment in normal condition, unlike the warm-blooded animals, which can react to maintain the optimum body temperature. For eg. the optimum range of temperature for the Black Tiger shrimp is between 28°C-30°C. Increase in temperature beyond 30°C increases the activity level and the metabolism. This also increases the growth rate. If the temperature still increases then the shrimp reaches a threshold of physical and nutritional tolerance, which is 33°C in poor quality water or 35°C in good quality water and remains stationary at the pond bottom.

If the environment does not improve the culture organisms may get infected by germs, swim in a disoriented way to the surface or due to exhaustion. If the temperature falls below 28°C, the metabolism reduces and so does the active behaviour and growth rate. Below 20°C, the shrimp will take less feed. Shrimps cannot tolerate a temperature less than 13°C.

In the semi intensive culture system, shrimps are more sensitive to temperature than in the extensive one because of the higher biomass and less water volume. During the rainy season, there is a greater possibility of occurrence of thermal stratification in pond water column, as well as the salinity (density) and dissolved oxygen stratification.

Water depth and water volume affect the thermal capacity of the pond and the extent of light penetration. It is related to fluctuation of planktonic algae and benthic algae.

It also influences the volume of the pond and therefore the ponds capacity to support the dissolved oxygen, influencing productivity, biomass and production yield.

Salinity

Salinity plays an important role in the growth of culture organisms through osmoregulations of body minerals from that of the surrounding water. For eg. the optimum range of salinity for black tiger shrimp is between 10 and 25 ppt, although the shrimp will accept salinity between 5 and 38 ppt. since its eurihaline character. The early life stages of both shrimp and prawn requires standard seawater salinities but while growing they can with stand to brackishwater or even to freshwater. However, for better survival and growth optimum range of salinity should be maintained in the aquaculture ponds.

Dissolved Oxygen

Atmospheric oxygen crosses the air-water boundary and dissolves in the water matrix. The only way that oxygen can be introduced from air to water is by diffusion. Atmosphere contains vast amount of oxygen, some of which diffuse into pond waters when they are unsaturated with oxygen. Likewise, oxygen is lost to the atmosphere when pond water have supersaturated with oxygen. The driving force causing net transfer of oxygen between air and water is the difference in the tension between oxygen in the atmosphere and oxygen in the water. Once equilibrium is reached i.e. oxygen tensions in air and water are the same, the net oxygen transfer ceases. Oxygen must enter or leave a body of water at the air-water interface and for the very thin film of water in contact with air, the greater the deficit or surplus, the faster oxygen will enter or leave the film. For undisturbed water, the net transfer of oxygen will depend upon deficit or surplus, the area of the air-water interface, the temperature and the time of contact. In general, the rate of diffusion of oxygen depends primarily on the oxygen deficit in water, the amount of water surface exposed to the air and the degree of turbulence.

Typically, dissolved oxygen is measured either in mg. per litre (mgI^{-}) or parts per million (ppm) with O ppm representing total oxygen depletion and 15 ppm representing the maximum or saturation concentration.

The solubility of oxygen in water decreases as the water temperature increases. It is interesting to note that oxygen appears to operate in a cyclic fashion. Having crossed air-water boundary, dissolved oxygen is utilized by aquatic organism to accommodate metabolism and is excreted as carbon dioxide (CO_2). The liberated CO_2 is used by, photosynthetic plant forms to regenerate oxygen within the pond. The aquatic organism again consumes much of this oxygen and some is returned to the environment. There appears to be a symbiotic relationship between the aquatic organisms and photosynthetic plant forms.

The oxygen cycle and hence oxygen balance can be affected by, what is known as the biochemical oxygen demand (B.O.D.) of the pond. Decaying plant and animal matter consume substantial amounts of oxygen in the decaying process. It is important to realize that the oxygen cycle and hence dissolved oxygen levels can be affected by changes in the surroundings; a cloudy day with little sunlight will reduce the photosynthetic oxygen contribution to dissolved oxygen. Similarly, unusually high temperatures will lower the solubility of oxygen in water and hence low dissolved oxygen. When a pond is in 'balance' dissolved oxygen will not vary erratically.

Oxygen is one environmental parameter that exerts a tremendous effect on growth and production through its direct effect on feed consumption and metabolism and its indirect effect on environmental conditions. Oxygen affects the solubility and availability of many nutrients. Low levels of dissolved oxygen can cause changes in oxidation state of substances from the oxidized to the reduced form. Lack of dissolved oxygen can be directly harmful to culture organisms or cause a substantial increase in the level of toxic metabolites. It is therefore important to continuously maintain dissolved oxygen at optimum levels of above 3.5 ppm.

There is above 21% oxygen content in the air. Air acts a big reservoir for oxygen concentration in water is limited by its solubility. The solubility of oxygen:

- decreases as the temperature increases.
- decreases exponentially with increase in salinity.
- decreases with lower atmospheric pressure and higher humidity.
- increases with depth.

Strategies to maintain optimum levels of DO would be to take advantage of major factors that increase DO and put into check the factors that decrease DO. Photosynthesis plays a major role in oxygen production; respiration of all living organisms in the pond is the major factor involved in oxygen consumption. Oxygen concentration in pond water exhibits a diurnal pattern, with the maximum occurring during the peak of photosynthesis in the afternoon and the minimum occurring at dawn due to nighttime respiration. The magnitude of DO fluctuation is small and occurs around the level of saturated DO when plankton density is low and increases as plankton density increases. Supplemental aeration is generally provided during nighttime when DO increases to levels below 4.0 ppm.

Photosynthesis of phytoplankton is the major contributor of DO during the day and diffusion accounts for increases when DO is below saturation at night. Diffusion at night can be tremendously facilitated with the use of aerators, which exposes more water surface to equilibrate with atmospheric oxygen. Through reverse diffusion, an aerator operated during the day will tend to remove supersaturated DO. The net effect is a milder diurnal fluctuations of DO similar to the conditions of low phytoplankton density. Such conditions are favorable for semi-intensive culture of prawn and shrimp.

Photosynthetic oxygen production is also significantly limited when a plankton die-off occurs. The phenomenon is commonly observed when a cyclone occurs. Under these conditions, flushing out decaying plankton, providing for additional aerators and aerating for additional hours may be necessary to maintain DO at optimum levels.

When plankton density is high, it has a shading effect which limits the penetration of sunlight in water thereby reducing photosynthetic oxygen production in the bottom of the water column. High plankton density often results from high nutrient loads and other these conditions, large quantities of feed and fecal wastes are found on the pond bottom. This causes an increase in bacterial population and metabolic activity in the bottom sediments, which are several orders of magnitude higher than that in the water column. Consequently, DO consumption is much greater in the bottom sediment. Limited light penetration and increased DO consumption in the bottom may cause significantly lower DO compared to the top layer of the water column. If this causes DO to deplete to lower than critical levels, disastrous effects on the prawns may happen. Limited light penetration (low secchi disc reading) can also cause differences in the temperature of the top and bottom layer. Temperature stratification usually occurs during calm and warm afternoons. Pond managers should avoid temperature differences of greater than 1°C.

It appears that the occurrence of cramps (curved-stiff) in prawns and shrimps, which may cause mortalities, is associated with sudden temperature changes. Circulating the pond water helps remove or minimize stratification by agitators.

It was found that the paddle wheel aerator is capable of elevating the dissolved oxygen level from 0.05 to 4.9 mg/l with in 4 hours in 0.5 ha. Pond. It was also suggested that the low dissolved oxygen values in the aquaculture ponds be improved rapidly by combination of aeration and water exchange.

PH (measure of acidity or alkalinity)

PH or the concentrations of hydrogen ions (H^+) present in pond water is a measure of acidity or alkalinity. The pH scale extends from 0 to 14 with 0 being the most acidic and 14 the most alkaline. PH 7 is a condition of neutrality and routine aquaculture occurs in the range 7.0 to 9.0 (optimum is 7.5 to 8.5). Exceedingly alkaline water (greater than pH 9) is dangerous as ammonia toxicity increases rapidly. At higher temperatures fish are more sensitive to pH changes.

It is an important chemical parameter to consider because it affects the metabolism and other physiological processes of culture organisms. A certain range of pH (pH 6.8 – 8.7) should be maintained for acceptable growth and production. But in semi- intensive culture, re-optimum range is better maintained between pH 7.4 – 8.5. pH 7 is the neutral point and water is acidic below pH 7 and basic above pH 7. pH changes in pond water are mainly influenced by carbon dioxide and ions in equilibrium with it. PH can also be altered by a) Organic acids, these are produced by anaerobic bacteria ("acid formers") from protein, carbohydrates and fat from feed wastes, b) Mineral acids such as sulfuric acid (acid-sulfate soils), which may be washed down from dikes during rains and c) Lime application.

Like DO, a diurnal fluctuation pattern that is associated with the intensity of photosynthesis, occurs for pH. This is because carbon dioxide is required for photosynthesis and accumulates through nighttime respiration. It peaks before dawn and is at its minimum when photosynthesis is intense. All organisms respire and produce Carbon dioxide (CO_2) continuously, so that the rate of CO_2 production depends on the density of organisms. The rate of CO_2 consumption depends on phytoplankton density. Carbon dioxide is acidic and it decreases the pH of water. Also, at lower pH, CO_2 becomes the dominant form of carbon and the quantity of bicarbonate and carbonate would decrease. The consumption of CO_2 during photosynthesis causes pH to peak in the afternoon and the accumulation of CO_2 during dark causes pH to be at its minimum before dawn.

The pH should be monitored before dawn for the low level and in the afternoon for the high level. The magnitude of diurnal fluctuation is dependent upon the density of organisms producing and consuming CO_2 and on the buffering capacity of pond water (greater buffer capacity at higher alkalinity). i.e., Diurnal fluctuation of pH is not great in pond water of higher alkalinity. An alkalinity above 20 ppm $CaCO_3$ is preferred in prawn/shrimp ponds. Intervention, such as flushing of ponds to reduce the pH, is advisable when the magnitude of diurnal fluctuation in pH is great.

Nevertheless, one should notice that the drastic fluctuation of pH would cause stress to culture organisms. Normally, it should maintain the daily fluctuation within a range of 0.4 difference. Control of pH is essential for minimizing ammonia and H_2S toxicity.

Ammonia

Ammonia is the second gas of importance in fish culture; its significance to good fish production is overwhelming. High ammonia levels can arise from overfeeding, protein rich, excess feed decays to liberate toxic ammonia gas, which in conjunction with the fishes, excreted ammonia may accumulate to dangerously high levels under certain conditions. Fortunately, ammonia concentrations are partially 'curbed' or 'buffered' by conversion to nontoxic nitrate (No_3^-) ion by nitrifying bacteria. Additionally, ammonia is converted from toxic ammonia (NH_3) to nontoxic ammonium ion (NH_4^+) at pH below 8.0.

Hardness

Numerous inorganic (mineral) substances are dissolved in water. Among these, the metals calcium and magnesium, along with their counter ion carbonate (CO_3^{-2}) comprise the basis for the measurement of 'hardness'. Optimum hardness for aquaculture is in the range of 40 to 400 ppm of hardness. Hard waters have the capability of buffering the effects of heavy metals such as copper or zinc which are in general toxic to fish. The hardness is a vital factor in maintaining good pond equilibrium.

Turbidity

Water turbidity refers to the quantity of suspended material, which interferes with light penetration in the water column. In prawn ponds, water turbidity can result from planktonic organisms or from suspended clay particles. Turbidity limits light penetration, thereby limiting photosynthesis in the bottom layer. Higher turbidity can cause temperature and DO stratification in prawn ponds.

Planktonic organisms are desirable when not excessive, but suspended clay particles are undesirable. It can cause clogging of gills or direct injury to tissues of prawns. Erosion or the water itself can be the source of small (1-100 nm) colloidal particles responsible for the unwanted turbidity. The particles repel each other due to negative-charges: this can be neutralized by electrolytes resulting in coagulation. It is reported that alum and ferric sulfate are more effective than hydrated lime and gypsum in removing clay turbidity. Both alum and gypsum have acid reactions and can depress pH and total alkalinity, so the simultaneous application of lime is recommended to maintain the suitable range of pH. Treatment rates depend on the type of soil.

Redox Potential (Oxidation-Reduction Eh)

Redox Potential is an index indicating the status of oxidation or reduction. It is correlated with chemical substances, such as O_2, CO_2 and mineral composed of aerobic layer, whereas H_2S, CO_2, NH_3, H_2SO_4 and others comprise of anaerobic layer. Microorganisms are correlated with the status of oxidation or reduction. With the degree of Eh, it is indicative of one of the parameters that show the supporting ability of water and soil to the prawn biomass.

In semi intensive culture photosynthetic bacteria (PSB) plays an important role through absorption and conversion of organic matter into the minerals and nutrients as a secondary production, compared to the primary production of algal population. PSB exist particularly due to low oxygen level and high intensity of light and can significantly improve the culture environment.

Water quality management

Water quality parameters should be monitored to serve as guide for managing a pond so that conditions that can adversely affect the growth of prawns can be avoided. In cases where problems are encountered, these parameters can help in the diagnosis, so a remedy can be formulated. Individual parameters usually do not tell much, but several parameters put together can serve as indicators of dynamic processes occurring in the pond.

The population of phytoplankton and microorganisms are major determinants of the level of oxygen and metabolites in the pond. The diet fluctuation of DO (including its vertical profile), pH and CO_2 serve as indicators of their population. Since CO_2 is the major factor affecting the dial fluctuation of pH, monitoring pH fluctuation may be adequate. Also, CO_2 is more difficult to measure.

Daily measurements are conducted at early hours i.e. 5-6 am and after noon measurements in the i.e. 2-3 pm. This represents the period before the start of photosynthesis and the peak of photosynthesis, respectively. Thus the maximal and the minima of these parameters occur during this period. The other parameters do not have a distinct dial pattern and therefore can be monitored only once a day, preferable at a common time. Feed and growth data need to be presented with water quality parameters, side by side. This is because algal blooms are consequences of nutrients from feeds and excess feed can cause the rapid deterioration of water quality.

Careful monitoring and data collection will remain useless unless it influences decisions regarding water management. This becomes more important as cost to implement various management schemes (aeration, water exchange, inputs) increase.

Most of the water quality problems can be solved with adequate water exchange. Thus, if large quantities of water suitable for aquaculture were available, monitoring would not be as critical and high production levels can be targeted. If water is limited, the risk of encountering water quality and disease problems increases as one goes for more intensive culture.

Water Exchange

When stocking density increases, it is of primary importance to have a dependable water supply and to maintain good water quality. So far, besides aeration, water exchange is still the most effective and widely employed method to maintain good water quality besides water quality enhancers like sanitizers, zeolite etc. Generally, water exchange is used to adjust salinity as desired, to remove excess metabolites, to keep algae healthy and producing ample oxygen and to regulate pond water temperature. The exchange rate varies with the production period, stocking density and total biomass, levels of natural productivity, turbidity and source and volume of water.

The principle of water exchange is to change the water in a way such that the water quality changes gradually instead of abruptly. In semi-intensive systems, frequent and sometimes even continuous water exchange at a small flowing rate is employed. Abrupt addition of large quantities of water in small ponds may result in sudden environment change, which subsequently can stress in culture organism. Therefore, massive water replacement is not recommended unless there is sudden die-off of plankton, critical low oxygen or after the application of chemicals. Continuous water exchange should be accompanied with running of paddlewheels to have the pond water fully mixed. Otherwise, it will cause great differences of water quality within a pond and heterogeneous distribution of culture organisms on the pond bottom.

Lowering the water level first and adding new water is not recommended, especially during daytime in summer. Increasing water temperature, while lowering water level, can reduce the capability of water to hold oxygen and hasten the degeneration of the pond bottom, leading to oxygen depletion. It is better to add new water first according to the predetermined exchange rate, have the paddlewheel running to homogenize water throughout the pond and then discharge water.

Both bottom and surface water discharge can be considered. Water quality in the bottom layer is generally worse than near the surface. Surface water should be discharged when there are scums, shrimp or prawn faeces and floating dead plankton are present. During and after showers, the lower density freshwater at the surface layer should be discharged to avoid salinity change.

The lowering of salinity more than 5 ppt, at each time, by the water exchange is not recommended. Drastic changes of salinity may alter the phytoplankton fauna and their population densities and lead to instability of the ecosystem.

Water exchange is the first method to improve pond management, except when

- Good quality of water is not available.
- A drastic change to the pond environment should be avoided.
- Culture organisms have been greatly weakened as a result of nutrition depletion and diseases.
- Ponds are being treated with chemicals and medicine.

While doing water exchange several parameters should be noticed such as pH value, salinity, temperature, turbidity and other parameters related to defining good pond environment.

In the first month of culture, the water cultivation is most important and therefore only low level of exchange water addition to fill up pond to take care of evaporation and seepage needs to be done instead of heavy water exchange. As the culture proceeds the degree of contamination is different and the purpose of water exchange is to decrease the contamination that can influence shrimp/prawn growth. Basically, the water exchange rate is determined by maintaining the optimum range of parameters discussed above and particularly on the amount of biomass.

Acceptable water quality can be achieved using the following pond management techniques:

- Controlled water exchange. Water exchange is done daily, as routine or extra exchange may be recommended to prevent onset of a problem or be recommended as integral to a crisis management.
- Co-ordinating water exchange and fertilization to maintain populations of algae.
- Avoid overfeeding through proper management of feeding trays.
- Aeration.
- Continual or periodic removal of accumulated organic material from the pond bottom.
- Maintenance of a high density bacterial flock i.e. probiotics combined with water circulation and aeration.

Water exchange alone does not in prove dissolved oxygen unless there is a significant difference in DO levels between intake and pond water. In farms that practice the step-wise water exchange method, it is beneficial to schedule filling of pond and incoming water is the maximum. An effective method of achieving desirable water quality during culture is a periodic reduction of 25-50 cm in the water level of the pond followed by heavy simultaneous exchange of water for 12-24 hours at the reduced depth. Since the water volume in the pond is reduced a greater percentage exchange is achieved in a shorter period. This is recommended to achieve the following:

Temporary improvements in DO caused by cropping algal populations below the "compensation depth" of the pond, which is the depth at which oxygen production and respiration by phytoplankton are equal. Light-limited phytoplankton below the compensation depth are net consumers of oxygen. The compensation depth roughly corresponds to twice the secchi disk depth. Prevent an increase of undesirable algal species. Water exchange alone can reduce the density of undesirable species. If fertilization and inoculation is done simultaneously with water exchange, culture of appropriate species can be achieved. The reduced pond volume amplifies the effects of fertilization.

Routine water exchange requirements are determined by shrimp/prawn/ biomass, feeding rates, phytoplankton and microbial densities and the presence or absence of aerators and sediment disposal systems. Daily water exchange is correlated with shrimp/prawn biomass and adjusted in accordance with DO and secchi disk readings.

Plotting morning and afternoon DO and secchi disk readings facilitates early detection of trends that would require adjustments in the basic water exchange program. Nighttime DO can be predicted by simply plotting DO readings at dusk and during the night, and extrapolating the results to dawn.

Although it is possible to maintain large biomass of shrimp with low rates of water exchange, pumping costs are generally less than 10% of the total cost of production and unless water resources limited, it is not advisable to reduce water exchanges rates in semi-intensive systems simply to minimize costs. Higher water exchange reduces the risk of water quality related disease problems. It is also one of the few management tools available for preserving survival in diseases animals that does not rely on use of chemicals.

Aeration

Paddlewheels are commonly used in semi-intensive shrimp/prawn culture and is one of the major capital cost item in the farm. The paddlewheel aerators are used to increase contact surface of water with air thereby increasing the area through which oxygen is absorbed by the water and to create a circular movement of the pond water. This has the following advantages:

- It increases the dissolved oxygen level of the water and prevents oxygen depletion during the night.
- It accelerates the diffusion effect of not only the oxygen, but also enables the capture or release of carbon dioxide. Carbon dioxide is important for culture of algae and therefore for maintenance of appropriate watercolor.
- It facilitates the volatilization of undesirable gases such as N_2, NH_3, CH_4 and H_2S.

- It reduces the daily fluctuation range of pH value.

- It accelerates the decomposition and mineralization of organic matter in water and soil and helps in the release of nutritive value of fertilizers.

- It diminishes the possible stratification of pH, DO, salinity and temperature in the pond water.

- It helps in mixing the pond water and maintenance of ideal conditions all over the pond.

- It increases turbidity when necessary.

As the pond water moves in a circular fashion the pond bottom is cleaned and the waste matter gets accumulated in the center and the corners. By this method most of the pond bottom is kept clean.

It is very important during application of chemicals or medical treatment with respect to distribution of chemicals/medicines throughout the pond and ensure to be careful in proper water exchange to reduce any side effects. Use of paddlewheels also has the advantage of accelerating the evaporation rate thereby increasing the salinity. This is however, an advantage in the condition of low salinity.

There is no hard and fast rule regarding the number of paddlewheels to be used in a pond because it is difficult to define the relation between biomass in the pond and the interaction of various water parameters.

The arrangement of paddlewheels in the pond is done to maximize circulation efficiency and minimize dead corner areas. The arrangement of paddlewheels should be to ensure anticlockwise movement of water in the pond in the Northern Hemisphere and clockwise movement of water in the pond in the Southern Hemisphere. This ensures that when bottom drainage arrangements are used, the efficiency of water exchange and draining out of waste product is improved since water when existing from the bottom of the reservoir in the northern hemisphere has an anticlockwise vortex, whereas in the southern hemisphere has a clockwise vortex.

Aerators are usually arranged parallel along the banks and about 5 to 10 m distant from the dikes depending upon the pond size. Each paddle wheel should normally separated by a distance of 30 m and 50 m for optimum efficiency of the paddle wheel. Avoid relocating paddle wheels during culture.

Removal of dissolved metabolic organics

One of the important stress factors is the increase of dissolved metabolic organics in culture water. It can increase ammonia and microorganisms.

Dissolved metabolic organics	Causes	Stress
(1) Decaying excess high protein feed	(a) Toxic ammonia nitrate	Animals stop eating, weakness and become susceptible to diseases.
(2) Dead larvae, organisms, algae	(b) Microorganisms - bacteria, fungi & protozoans	Lower water quality
(3) Animals excreta, urine	(c) BOD (Biological oxygen demand)	

This explains why water quality deterioration could quickly cause a high mortality rate. To prevent the buildup of dissolved organics, frequent partial to total water change is necessary; or the pollution could be reduced by the chemically removing the pollutants by adsorption using activated carbon.

The best way to facilitate the removal of metabolic wastes in a pond is by flushing out water from the bottom. Constantly maintaining high DO in the pond through supplemental aeration and water exchange, enhances nitrification. Nitrification is a major mechanism for ammonia removal in well-aerated ponds. Paddlewheel aerators are usually operated during dark (7 pm to 7 am) when oxygen depletion is likely to occur and at noon (12 noon to 2 pm) when temperature and oxygen stratification can become significant.

Phytoplankton management

Phytoplankton play a significant role in stabilizing the whole pond ecosystem and in minimizing the fluctuations of water quality. A suitable phytoplankton population enriches the system with oxygen through photosynthesis during day light hours and lowers the levels of CO_2, NH_3, NO_2 and H_2S. A healthy phytoplankton bloom can reduce toxic substances since phytoplankton can consume NH_4 and tie-up heavy metals. It can prevent the development of filamentous algae since phytoplankton can block light from reaching the bottom. A healthy bloom also provides proper turbidity and subsequently stabilizes shrimp and reduces cannibalism. It decreases temperature loss in winter and stabilizes water temperature.

Pond bottom treatment

For farms adopting advanced technology, it is necessary that pond bottom should be completely dried and aerated to get rid of toxic gases.

Many ponds in low-lying areas cannot be completely drained and dried. To overcome this, Aquafarmers apply waste digesters to the ponds. The digesters are harmless bacteria (probiotics) and enzymes that consume organic matter on the pond bottom.

After the application of digesters farmers apply a disinfectant, either organic silver or organic iodine. Copper sulphate is not used as a disinfectant now a days as it is not biodegradable and accumulates in the pond upto levels that are toxic to aquatic life. Organic silver is highly effective against bacteria and viruses and its toxicity to aquatic life is very low. Organic silver is applied at the rate of 18 litres (4 gallon) per hectare after lowering the water depth to 12 inches. Seven days after the application, this disinfectant disintegrates, so there is no need to flush the pond. Organic silver also prevents the development of algae that grows on shells.

Organic iodine, can cure gill or shell diseases, kills bacteria on contact and has low toxicity. Its effect can be noticed within 24 hours and the pond bottom can be disinfected without emptying the pond. The suggested dosage is 5 ppm to 10 ppm. Its affectivity lasts for two to three days compared to about seven days in the case of organic silver.

Nitrogen Metabolites

Large quantities of organic matter originating from the heavy feed load and feacal matter accumulate in aquaculture ponds. These undergo oxidation-reduction reactions leading to decomposition, mainly through the action of bacteria. Different forms of inorganic nitrogen like ammonia, nitrite and nitrate are produced during decomposition.

Maintaining water quality and preventing diseases

Environmental conditions vary considerably at different times of the year and the bacterial and fungal, load of seawater also varies. During the dry moths; there is less dilution of organic and toxic pollutants from human and industrial wastes. During this time the absence of rains also reduces water exchange between clean seawater and polluted coastal water. The result is a rise of viral, bacteria, protozoa, fungi and toxic pollutants in the water. This is partially upset during the hot summer months by phytoplankton and zooplankton blooms, which assimilate some of the bacteria and toxic substances. Under such conditions, cultured animals become vulnerable to infection. They are stressed by the following:

- Overcrowding in captivity.
- Temperature fluctuation of water, especially during water change (A one-degree Celsius difference can cause stress).
- A temporary decline in dissolved oxygen level due to power failure.
- Increase of free-carbon dioxide, un-ionized ammonia and organics due to decaying excess feed and dead animals.
- Physical manhandling during water change.
- Poor nutrition – improperly fed fish and prawn.
- The high level of toxic pollutant in seawater that may contain heavy metals such as copper, zinc, lead, nickel, mercury and chemicals like poly-chlorinated biphenyl compounds, chlorinated hydrocarbons such as DDT and other pesticides.

While there is no known practical way to remove these pollutants. Effect should be made to limit these stress-inducing factors to keep the animals strong enough to fight infection. Healthy animals, do not easily succumb to diseases. Where adequate filtration is not possible, treatment of water is suggested to lower the bacteria and fungal load of the water.

Self-pollution as a possible factor

When the accumulation of nutrients within ponds is high, self-pollution of the culture environment reduces production, frequently as a result of a severe disease-outbreaks. Although, in some cases, production losses can be linked back directly to disease-outbreaks, it is often difficult to separate the effect of disease and poor water quality. Disease-outbreaks occur when (1) a pathogen infects a population previously not exposed to the microorganism. or (2) poor culture conditions weaken resistance to pathogens permanently present in the culture environment. Outbreaks of new infectious diseases will be difficult to prevent as long as there are no strict regulations for transfer of culture stocks between regions. From a practical point of view, more attention should be paid to culture conditions, with special attention to water quality.

Some farms, experienced a collapse in production from 15-18 Mt ha^{-1} to 4-6 Mt ha^{-1}, but were able to restore production levels of 10-12 Mt ha^{-1} year^{-1} on a continuous basis. These farmers concentrated on water quality management, introducing measures such as high levels of pond flushing (>30% day^{-1}) excavation and tilling of pond bottoms upon harvest, emergency aeration and the use of drugs, chemicals and biological agents to suppress disease-outbreaks. Farmers apply these measures empirically.

Details of the importance of physico-chemical parameter and microbiological aspects in aquaculture ponds.

S. No	Parameter	Purpose	Equipment Required	Chemicals and Glassware Required
I	Water quality parameters			
1	Temperature	Maintenance of optimal temperature, fluctuations at high level, leeds to severe effect on entire body of pond and leeds thermal stress on shrimp, algal crash etc. (28 - 32°C)	Mercuric thermometer / Digital thermometer	----
2	Salinity	Eurihaline; tolerance capacity with broad range of salinity (10 - 25 ppt)	Clinometers (Refract meter)	Titrimetric method of knewdson's for standardization of salinometer
3	PH	Little bit basic conditions are favourable (7.4 – 8.5)	Digital PH meter / pH pen	Standardized by Titrimetric method
4	Transparency	Optimal maintenance of plankton density (30 - 40 cm)	Sacchi disc	Primary productivity estimation by dark white bottle method by C^{14} method
5	Dissolved Oxygen	Is the main requirement for physiological & biochemical activities of living things (> 3 mg/l)	D.O. Meter/ Wrinklers method	Chemical and Glassware required burette, pipette, conical flasks, D.O bottles (reagent bottles), beakers etc.
6	BOD	It is necessary to estimate the requisite of oxygen content by the enclosed body of water	D.O method/ Wrinklers method	Chemical and Glassware required burette, pipette, conical flasks, D.O bottles (reagent bottles), beakers
7	COD	The amount of oxygen required for the complete oxidation of all organic/chemical components in the pond environment	Oxidized method	Chemical & Glassware required reflexor, hotplate etc.

Cont….

8	Nitrate – N	The nutrient content is very high leads to heavy blooming of algae	Spectrophotometer meter/ Calorimeter/kits (YSI, Merck, Loba)	Chemicals & Glassware
9	Nitrite – N	It is an toxic constituent	Spectrophotometer/ Calorimeter/ kits (YSI, Merck, Loba etc.)	Chemicals & Glassware
10	Ammonia–N	It is an toxic constituent	Spectrophotometer/ Calorimeter/ kits	Chemicals & Glassware
11	Phosphate–P	Nutrient	Spectrophotometer/ Calorimeter/ kits	Chemicals & Glassware
12	Hydrogen sulphide	Toxic and makes anoxic conditions	Spectrophotometer/ Calorimeter/ kits	Chemicals & Glassware
13	<u>Sediment analysis</u>			
	a. Sediment organic matter	It shows how much of organic matter and organic carbon produced in the pond bottom by the shrimp farming activity.	Titrimetric method	Chemicals & Glassware
	b. Sediment composition	It exhibits the ratio's of sediment components i.e., sand, silt & clay	Pipette method	Chemicals & Glassware
II	<u>Biological</u>			
A.	<u>Bacteriological</u>			
1	TVC (Total Viable count of Bacteria)	It reveals the total bacterial forms that harbour the pond environment	Laminar flow chamber, oven, incubator, autoclave, petridishes, test tubes, conical flasks, test tube stand, micropipette, beakers, digital colony counter.	TGY media (Tryptone Glucose Yeast extract Agar)
2	TVLO (Total Vibrio like organizers)	It reveals the total bacterial forms that harbour the pond environment	Laminar flow chamber, oven, incubator, autoclave, petridishes, test tubes, conical flasks, test tube stand, micropipette, beakers, digital colony counter.	TCBS media (Thiamine Citrate, Bile sucrose salt Agar)
3	Other pathogenic bacteria	It reveals the total bacterial forms that harbour the pond environment	-DO-	Different media for respective various bacteria

B.	Virology			
1	Dot Blot method	Viral diseases like WSV, MBV etc.	Kits	-
2	PCR method	Viral diseases like WSSV, MBV etc.	Primers, Thermal cyclar, UV laminar flow chamber, electrophoresis unit, UPS system etc.	-
3	Histopathology	Viral diseases like WSV, MBV etc.	Microtome, staining & distaining equipment and stains.	-
C.	Ectocommensal Parasites	Like Zoothamnium, Vorticella, Fungi etc.	Simple binocular microscope and Compound monocular microscope with CCTV.	-

Details of the analysis methods and the required equipment for the physico-chemical parameters and microbiological aspects of water and sediment in aquaculture ponds.

S. No	Parameter	Methodology	Equipment / Chemicals
1	Temperature	Visible	Digital Thermometer
2	Salinity	Visible/titration	Refractometer
3	PH	Visible/titration	pH pen/meter
4	Alkalinity	Titrimetric method	Glassware & Chemicals
5	Transparency	Light intensity	Sacchi disc
6	Turbidity	Tendol effect principle	Tindalometer
7	Dissolved Oxygen	Visible/titrimetric method (Wrinklers)	YSI DO meter
8	BOD	Visible/titrimetric method (Wrinklers)	YSI BOD probe
9	COD	Reflection method	Reflexor unit
10	Nitrate – N	Wood et al. (1967) method American Public Health Association (APHA)	Spectrophotometer meter (Chemicals & Glassware)
11	Nitrite – N	Wood et al. (1967) method (APHA)	Analysis kits (Merck, Loba, YSI, BDH etc.)
12	Ammonia – N	Soloranzo (1969) (APHA)	Analysis kits (Merck, Loba, YSI, BDH etc.)
13	Phosphate – P	Murphy & Riley, 1962 (APHA)	Analysis kits (Merck, Loba, YSI, BDH etc.)
14	Hydrogen Sulphide	p-Phenylene Diamine Hydrochloride (APHA)	Analysis kits (Merck, Loba, YSI, BDH etc.)
15	Sediment Organic Matter	Gaudette et al. method Titration	Glassware & Chemicals
16	Sediment Composition	Pipette analysis	Glassware & Chemicals

Standards of Water Quality for Aquaculture

ITEMS	VALUE OF STANDARD
1. Colour, offensive smell.	Fish, shrimp, shell fish and kelp should not have odd colour, odd offensive smell.
2. Floating material.	No oil film and floating foam should appear on the water surface.
3. Suspended material (mg/l).	The amount added to human beings should not surpass 10, and the suspending materials sunk to the bottom of the water should not be harmful to fish, shrimp and shellfish.
4. pH value.	Freshwater 6.5-8.5, seawater 7.4-8.5.
5. Dissolved oxygen	In successive 24h, above 16 h should be higher than 5 mg/l, and the other time should not be lower than 3 mg/l.
6. Biochemical Oxygen Demand (5 days, 20°C).	Should not surpass 5 mg/l, frozen period should not surpass 3 mg/l.
7. Total colonial bacillus.	Should not be greater than 5000/L (and should not surpass 500 pieces/L)
8. Mercury.	<0.0005 mg/l
9. Cadmium	<0.005 mg/l
10. Lead	<0.05 mg/l
11. Nobelium	<0.1 mg/l
12. Copper	<0.01 mg/l
13. Zinc	<0.1 mg/l
14. Nickel	<0.05 mg/l
15. Arsenic	<0.05 mg/l
16. Cyanide compound	<0.005 mg/l
17. Sulphur compound	<0.2 mg/l
18. Fluorinated compound	<1 mg/l
19. Unionised ammonia	<0.02 mg/l
20. Kjeldhal nitrogen	<0.05 mg/l
21. Volatised phenol	<0.005 mg/l
22. Yellow phosphorus	<0.001 mg/l
23. Petrolium	<0.05 mg/l
24. Acrylonitrile	<0.05 mg/l
25. Acrylaldehyde	<0.02 mg/l
26. BHC	<0.002 mg/l
27. DDT	<0.001 mg/1
28. Malathion	<.005 mg/l
29. Pentachlorophenol	<0.01 mg.l
30. Rogor	<0.1 mg/l
31. Methamidophos	<1 mg/l
32. Parathion methyl	<0.0005 mg/l
33. Carbofuran	<0.01 mg/l

Water quality parameters for shrimp farming

Water parameter	Optimum level
Temperature	26-33 C
Salinity	10-25 ppt
Dissolved oxygen	>3.0 ppm
pH	7.5-8.5
Total Ammonia Nitrogen	<1.0 ppm
Total Nitrate Nitrogen	<5.0 ppm
Nitrite Nitrogen	<0.01 ppm
Sulphide	<0.03 ppm
Biological Oxygen Demand	< 10 ppm
(BOD)	<70 ppm
Chemical Oxgen Demand (COD)	25-45 cm
Sacchi disc visibility	