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Evaluation of Fish Cultivation Water Quality in Aquaponic Systems with Different Aeration Systems

Evaluasi Kualitas Air Budidaya Ikan pada Sistem Akuaponik dengan Sistem Aerasi yang Berbeda

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Abstract

Aquaponics is a sustainable aquaculture technology that integrates a recirculation aquaculture system with plant cultivation in one system. The aquaponic system can be a solution that can be used as an intensive fish farming system and increase fish farming production. However, intensive cultivation will cause dissolved oxygen concentration to decrease rapidly. It will affect the water's quality, so an aeration system is needed to maintain the balance of dissolved oxygen in the water. The difference in the use of aeration systems in aquaponic systems will certainly provide different water quality results. So, this study aims to determine the type of aeration system most effective for cultivation activities in the aquaponic system. The method used in this study is a descriptive exploration of various literature and research results that have been published, both from books, national journals, and international journals. Based on a comparison of the results of previous studies, it can be concluded that aeration technology with microbubble sizes such as MNB and FBs can increase oxygen higher and more stable than conventional and venturi aeration technologies. The application of MNB and FBs aeration technology can produce water quality with dissolved oxygen concentration >7 mg/L, reduce ammonia concentration to <0.01 mg/L, nitrate concentration to <0.6 mg/L, and phosphate concentration <0.3 mg/L, as well as reducing total solids to 16% and volatile solids to 32%.

Keywords: Aquaponics, Aerations, Water quality, Dissolved oxygen

Abstrak

Akuaponik merupakan sebuah teknologi akuakultur yang berkelanjutan dengan mengintegrasikan budidaya perikanan sistem resirkulasi dan budidaya tanaman dalam satu wadah budidaya. Sehingga sistem akuaponik dapat menjadi solusi untuk digunakan sebagai sistem budidaya perikanan intensif dan meningkatkan produksi budidaya ikan. Namun, budidaya intensif akan menyebabkan konsentrasi oksigen terlarut cepat berkurang dan akan berpengaruh terhadap kualitas air yang ada di dalamnya. Sehingga penerapan sistem aerasi sangat dibutuhkan sebagai upaya untuk menjaga keseimbangan oksigen terlarut perairan. Perbedaan penggunaan sistem aerasi pada sistem akuaponik tentu akan memberikan hasil kualitas air yang berbeda. Sehingga penelitian ini bertujuan untuk mengetahui jenis sistem aerasi yang paling efektif digunakan untuk kegiatan budidaya dalam sistem akuaponik. Metode yang digunakan dalam penelitian ini yaitu deskriptif eksploratif dari berbagai literatur dan hasil-hasil penelitian yang telah dipublikasikan, baik dari buku, jurnal nasional ataupun jurnal internasional. Berdasarkan perbandingan dari hasil penelitian terdahulu dapat ditarik kesimpulan bahwa teknologi aerasi dengan ukuran gelembung mikro seperti MNB dan FBs dapat meningkatkan oksigen lebih tinggi dan stabil daripada teknologi aerasi konvensional dan venturi. Penerapan teknologi aerasi MNB dan FBs dapat menghasilkan kualitas air dengan konsentrasi oksigen terlarut >7 mg/L, mengurangi konsentrasi amonia hingga $\leq$0,01 mg/L, konsentrasi nitrat sebesar $\leq$0,6 mg/L, dan konsentrasi fosfat $\leq$0,3 mg/L, serta pengurangan total solid hingga 16% dan volatile solid hingga 32%.

Kata kunci: Akuaponik, Aerasi, Kualitas air, Oksigen terlarut

1. Introduction

Aquaponics is the controlled cultivation of aquatic organisms in freshwater or marine environments for human food needs (Yaparane et al., 2024). The increasing human demand for fishery products, which are food sources, has significantly impacted the rapid growth of the fishery industry (Sarkar et al., 2022). However, the increase in the potential of the fisheries industry is not supported by the decreasing land area and water quality, thus requiring more efficient fisheries technology in utilizing space and aquatic resources, one of which is the application of aquaponics systems (Andriani & Zahidah, 2019).

Aquaponics is an aquaculture technology that has the potential to enhance sustainable food production by integrating recirculating aquaculture and plant cultivation within a single cultivation system (Wongkiew et al., 2018). In the aquaponics cultivation system, the nutrient content of the water, such as nitrogen (N) and phosphate (P), produced from the fish farming process will be absorbed by the plants, thereby creating a better aquatic environment for fish growth (Diver, 2006). Chen et al. (2016) explain that several types of vegetables, such as water spinach, beet spinach, tomatoes, radishes, and lettuce, have commonly been used as hydroponic plants to utilize N and P sources from nutrient-rich wastewater for their growth. Thus, the aquaponics system can be a solution that can be used as an intensive fish farming system and to increase fish farming production (Tezlaff & Heidinger, 1992).

However, intensive fish farming can increase waste from excretion due to high fish density (Shafrudin et al., 2006). If the fish density is too high, the dissolved oxygen concentration will quickly decrease, affecting the water quality. Poor water quality can cause a decrease in fish appetite, a decrease in fish growth rate, trigger diseases in fish, and reduce the survival rate of the fish being kept (Zahidah et al., 2018). Parameters such as dissolved oxygen in water are important factors that determine water quality (Farida et al., 2017).

Dissolved oxygen in the maintenance medium plays a role in the oxidation and reduction processes of organic and inorganic materials by nitrifying bacteria to reduce the pollution load in the cultivation container (Andriani et al., 2023). Dissolved oxygen in the aquaponics system cannot be met by relying solely on the natural diffusion process. Therefore, implementing an aeration system is highly necessary to maintain the balance of dissolved oxygen in the water (Afdillah et al., 2020). The difference in using aeration systems in aquaponics systems will yield different water quality results. Therefore, this research aims to determine the most effective type of aeration system for aquaponics cultivation activities that can maintain the quality of the cultivation water, resulting in optimal fish and plant productivity.

2. Material and Method

The method used is a descriptive-exploratory method. This method employs literature from previous research in national and international journals: Google Scholar and Research Gate. The keywords used include aquaponic systems, water quality, and aeration.

3. Result and Discussion

3.1. Aquaponics System

The aquaponics system is a simple integrated cultivation system between aquaculture and hydroponics, utilizing feed leftovers and fish metabolic waste as plant nutrient sources (Stathopoulou et al., 2018). Aquaponics is a freshwater ecosystem where organisms like fish, plants, and bacteria interact with abiotic elements like water, air, and growing media. Fish are fed in the aquarium, and their waste, which contains much ammonia from the food, is converted by bacteria and other microorganisms into nutrient-rich fertilizer containing nitrates and ammonium (Puspa & Rawal, 2024). In this case, plants act as biological filters that will filter nutrients from fish farming waste, which they will use to grow, and the filtered water will become cleaner for the survival of the fish (Andriani & Zahidah, 2019). The primary function of this system is to optimize water function and bioremediation of water using plants in the fish farming system (Nugroho et al., 2012).

Fish metabolic waste contains ammonia compounds that can cause a decline in water quality. The amount of ammonia contained in a body of water is directly proportional to the amount of feed given (Shobihah et al., 2022).

The aquaponics system reduces ammonia by absorbing wastewater or effluent using plant roots, so the absorbed ammonia undergoes an oxidation process with the help of oxygen and bacteria, converting ammonia into nitrate (Widyastuti, 2008). In aquaculture activities with a system without water replacement, bacteria play an important role in removing ammonia particles through nitrification (Rully, 2011).

According to Andriani & Zahidah (2019), aquaponics system has several advantages, including: 1) Zero environmental impact, aquaponics system can be environmentally friendly because it produces high-quality fish and plants without using artificial fertilizers, pesticides, or herbicides. 2) Water-saving: Water use in aquaponics can be 90% more efficient than conventional farming. 3) Easy to apply because it can be built in any size, in various locations, and according to needs. 4) Economic because in one cultivation cycle, it can produce two commodities at once: plants and fish, making it more efficient than conventional cultivation, and 5) Producing good water quality for fish growth.

3.2. Types of Aquaponics System

According to Assaffah & Primaditya (2020), the aquaponics system is an advanced system of hydroponics that involves several designs, such as DeepWater Culture (DWC), Nutrient Film Technique (NFT), and media-based grow bed. Deep Water Culture (Figure 1) is one of the aquaponics designs that still belongs to the raft model group (raft technique) (Sastro, 2015). According to Shobihah et al. (2022), the aquaponics system with DWC design places plants in net pots inserted into holes on top of a polystyrene raft. The position of the plant roots hangs at the water surface, which comes from the fish maintenance tank and has undergone a filtration process.

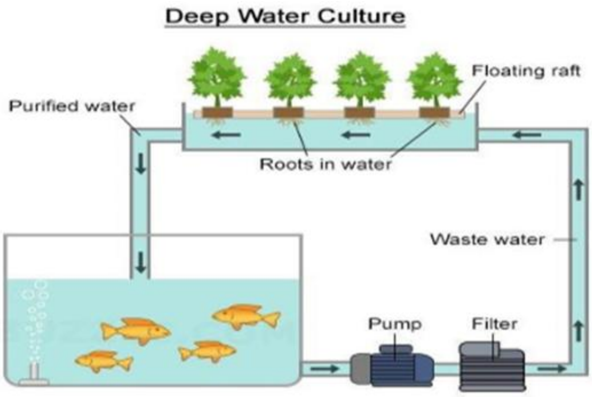

Figure 1. Schematic design of Deep Water Culture (DWC) aquaponics system
Source: Puspa & Rawal (2024)

Nutrient Film Technique is one of the most used systems in aquaponics. This design system involves using PVC pipes as the primary support for the plants. Plants are placed in the holes of the PVC pipe with the help of net pots or plastic cups to prevent them from falling or sinking (Andriani & Zahidah, 2019). In the pipe, water from the fish maintenance tank, which has undergone filtration, as shown in Figure 2, is circulated. NFT designs generally have a tiered system to utilize small land areas and accommodate more plants (Shobihah et al., 2022).

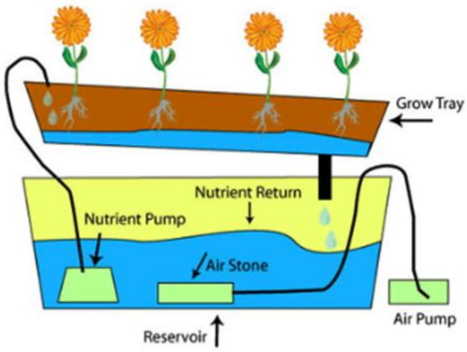

Figure 2. Schematic design of Nutrient Film Technique (NFT) aquaponics system
Source: Puspa & Rawal (2024)

The aquaponics system with a media bed design is the most commonly used because it is a viable alternative for small-scale systems and can be applied to various types of plants (Maucieri et al., 2018). This design is simple, space-efficient, and relatively inexpensive to construct (Shobihah et al., 2022). According to Assaffah & Primaditya (2020), in an aquaponics system with a media bed design, water from the fish tank is pumped directly into the growing media so it does not need to be stored in a biofilter (Figure 3). Because this design uses a substrate that provides a sufficient surface area for the growth of nitrifying bacteria and physical filtration, it eliminates the need for a biofilter (Maucieri et al., 2018).

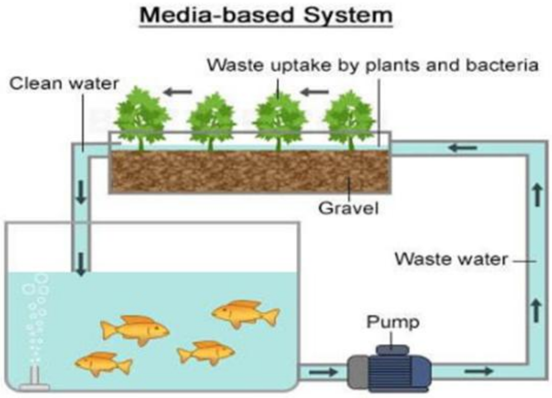

Figure 3. Schematic design of media-based grow bed aquaponics system
Source: Puspa & Rawal (2024)

3.3. Factors in Aquaponics Productivity

Water quality is an important factor in fish farming, especially the physical and chemical parameters of water that must be considered in an aquaponics system (Arthanawa et al., 2021). The main parameters that must be monitored include dissolved oxygen, pH, ammonia, nitrite, nitrate, and phosphate (Farida et al., 2017). Maintaining water quality is crucial for the sustainability and efficiency of aquaponics systems (Estim et al., 2020). So that fish, plants, and nitrifying bacteria can survive and thrive, the water quality criteria must be balanced. However, many issues are related to the ideal water quality criteria for productive aquaponics cultivation, such as the inconsistency of water quality parameters (Nair et al., 2024). In addition, according to Andriani & Zahidah (2019), 3 factors can affect productivity in an aquaponics system, including physical, biological, and other supporting aspects.

Physical aspects are supporting factors for the success of aquaponics, which include the recirculation system, the use of filters, and the construction design of the aquaponics system itself. The recirculation system can maintain a good cultivation environment so that fish growth can be optimal, and this system is related to improving water quality in wastewater treatment, especially from its biological aspects (Andriani & Zahidah, 2019).

Filters are a technology that can be used in aquaponics systems to reduce substances that can lower the water quality in cultivation ponds. Effective water filters to improve aquaculture water quality include physical, chemical, and biological filters. Water is filtered through a physical filter so that physical impurities are immediately filtered out, then the water enters a chemical filter that will absorb the toxic substances in the water, and finally, the water passes through a biological filter. In that filter, organic materials are converted by decomposing bacteria into inorganic materials. Therefore, using filters with the right composition can produce good water quality for cultivation activities, especially in increasing the productivity of the aquaponics system (Andriani & Zahidah, 2019).

Aquaponics systems' design and construction are diverse, ranging from DWC, NFT, and media bed designs. Currently, these three designs are commonly used. Different mechanisms within aquaponics systems with different designs will undoubtedly result in varying productivity (Shobihah et al., 2022). The aquaponics system uses a recirculation system, and filter media was applied by Andriani et al. (2018). In that study, the filter media of silica sand, gravel, and activated carbon effectively improved water quality to support aquaponics productivity.

Biological aspects include the selection of plants, fish, and density. Plants in the aquaponics system serve as biofilters, which are expected to improve water quality, thereby supporting cultivation activities. The plants used in aquaponics systems are generally horticultural plants, such as vegetables, with a short harvesting time (Andriani & Zahidah, 2019). The difference in the types of plants used in the aquaponics system will also result in varying aquaponics productivity because every plant has a different ability to utilize nutrients in the cultivation medium (Utami et al., 2019).

Several types of fish have commonly been cultivated in aquaponics systems, including catfish, tilapia, carp, koi, goldfish, barramundi, and rainbow trout (Andriani & Zahidah, 2019). The difference in the types of fish used also affects productivity in the aquaponics system. This is because every kind of fish has different amounts of waste from leftover feed and feces (Hasan et al., 2018). In addition, fish density also affects productivity in the aquaponics system. The high fish density will be directly proportional to the additional feed from outside, and it will also increase the excretion of waste produced by the fish, which will lead to a decrease in water quality.

The differences in plant types combined with koi fish in an aquaponics system have been conducted by Utami et al. (2019), who used lettuce, pak choy, and water spinach with varying results. For instance, pak choy was more effective in reducing ammonia by up to 32.03%, lettuce was more effective in reducing nitrate by up to 12.7%, and pak choy could increase phosphate by 122.6%. Additionally, Hasan et al. (2018) conducted aquaponics research with a combination of water spinach and three different types of fish, including catfish, tilapia, and koi. The results of the study showed different productivity levels, with the highest fish weight gain obtained from the combination of catfish and water spinach, achieving a growth of 7.8±1.18 g, and the highest growth of water spinach was obtained from the maintenance with koi, resulting in a biomass of 30.40±5.59 g.

In addition to physical and biological aspects, other factors will influence the success of the aquaponics system, one of which is the addition of probiotics. The addition of probiotics in the aquaponics system is closely related to the quality of the cultivation water used; by adding probiotics to the aquaponics system, the quality of the cultivation water can be improved because probiotics contain several types of microorganisms that can enhance the decomposition of cultivation waste (Andriani & Zahidah, 2019) as in the study by Zahidah et al. (2018) which used the Red Water System (RWS) probiotic in catfish farming within an aquaponics system. The study results showed that adding RWS probiotics to the aquaponics system did not increase the concentrations of ammonia, nitrate, and phosphate. The lowest ammonia, nitrate, and phosphate values were obtained in the aquaponics experimental group with RWS 10 µL·L-1/week (Treatment D). Treatment D had the lowest average ammonia level at 0.50 ppm, with nitrates reduced by 60.78%, and the temperature and pH remained relatively unchanged.

3.4. Aeration

Aeration adds oxygen to the water to increase dissolved oxygen concentration (Djaelani et al., 2022). Aeration functions to expand the contact area between air and water so that oxygen in the air can enter the surface of the water (Mohan et al., 2022). According to Petersen & Walker (2002), the function of an aerator is similar to that of "lungs," which is to introduce oxygen into the water to absorb carbon dioxide, especially for intensive farming systems. The principle of aeration is to combine water with air so that the water can come into direct contact with the oxygen in the air. Aeration is a physical working mechanism because it has more mechanical elements than biological elements (Djaelani et al., 2022).

3.5. Types of Aerators

Various aerators have been developed over the years to improve the efficiency of the oxygen mass transfer process and maintain dissolved oxygen levels in the water. According to Lekang (2013), aerator types can be classified into three types: Gravity aerator, water falling under the force of gravity, and air being mixed into it. This type of water is needed with natural pressure or can be pumped upwards to the aerator. The type of aerator that uses this principle is a packed column aerator (Figure 4).

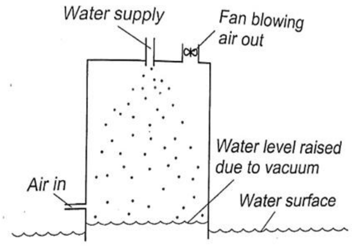

Figure 4. Packed column aerators
Source: Lekang (2013)

This type of water is sprayed into the air with a mechanical device. This type has the same principle as a fountain because it creates a large surface area, allowing gas exchange. One example of a surface aerator is the use of a rotating wheel with a paddle type, commonly known as a Paddlewheel (Figure 5)

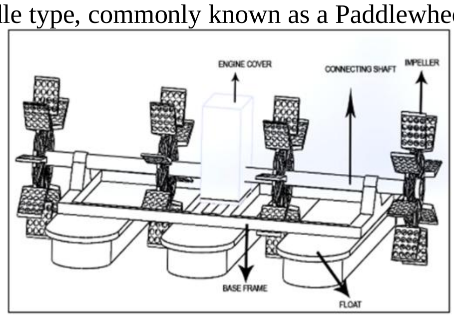

Figure 5. Packed well
Source: Tanveer et al. (2018)

In subsurface aerators, air is directed below the water surface, creating air bubbles that rise to the surface. These air bubbles create significant gas exchange within the water. A diffuser is one type of aerator commonly used as a bottom surface aerator (Figure 6).

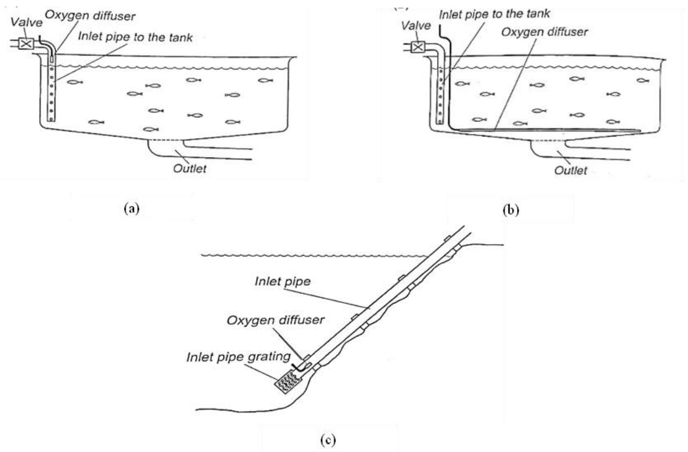

Figure 5. Oxygen diffuser in the inlet pipe of the tank (a); On the bottom of the tank (b), In the inlet pipe to the farm (c)
Source: Lekang (2013)

3.6. Water Quality in Aquaponics System with Different Aeration System

Water quality has a vital role in the fisheries sector, especially for aquaculture activities and the productivity of aquatic animals. The influence of water quality on aquaculture activities is very important, so farmers must monitor water quality parameters (Dauhan et al., 2014). Poor water quality will reduce fish appetite, delay growth, make them susceptible to diseases, and can cause fish death (Zahidah et al., 2018). The differences in aeration systems applied in aquaponics systems can result in variations in water quality within those cultivation systems. Several studies on aquaponics cultivation systems with different aeration system applications are shown in Table 1.

Table 1. Various applications of different aeration systems in aquaponics systems

No	Types of Aeration	Research	Result
1	Conventional aeration/blower	Zahidah et al. (2022)	The aquaponics system with a combination of comet fish and water spinach plants that applies conventional aeration/blower produces water quality with a dissolved oxygen concentration of 6.96 mg/L, an ammonia concentration of 0.02 mg/L, and a nitrate concentration of 0.59 mg/L.
2	Conventional aeration/blower	Naomi et al. (2020)	Water quality in the aquaponics system with conventional aeration application resulted in a dissolved oxygen concentration of 6.48 mg/l, an ammonia concentration of 0.03 mg/L, a nitrate concentration of 0.587 mg/L, and a phosphate concentration of 0.370 mg/L.
3	Venturi aeration	Hamdani et al. (2022)	Water quality in the aquaponics system with the application of venturi aeration resulted in a dissolved oxygen concentration of 5 mg/L, a pH of 7.5, ammonia at 0.02 mg/L, nitrate reached 50 mg/L, and phosphate at 10 mg/L.
4	Fine Bubbles Generator (FBs)	Naomi et al. (2020)	Water quality produced from the application of FBs in the aquaponics system with a combination of stipped catfish and water spinach plants is a temperature ranging from 24.2-27°C, a dissolved oxygen concentration reached 7.94 mg/L, an ammonia concentration of only 0.01 mg/L, a nitrate concentration of 0.602 mg/L, and a phosphate concentration of 0.229 mg/L.
5	Fine Bubbles Generator (FBs)	Putra et al. (2020)	The application of FBs in an aquaponics system with a combination of stipped catfish and water spinach plants resulted in a pH value ranging from 6.84-7.34, a temperature range of 23-28.5°C, a dissolved oxygen concentration reached 7.06 mg/L and an ammonia concentration of only 0.0027 mg/L.
6	Fine Bubbles Generator (FBs)	Zahidah et al. (2022)	The concentration of dissolved oxygen in the aquaponics system with a combination of comet fish and water spinach using FBs was 7.83 mg/L, with a temperature range of 24.4-26.5°C and pH of 6.98-8.07, as well as ammonia and phosphate concentrations of 0.002 mg/L and 0.316 mg/L, respectively.
7	Micronanobubbles Aeration (MNB)	Marcelino et al. (2023)	The application of Micronanobubbles Aeration (MNB) in aquaponics systems can increase dissolved oxygen levels up to 9.31 mg/l without causing any side effects on other components of the aquaponics system. And a reduction in total solids by up to 16% and volatile solids by up to 32%.

Dissolved oxygen is one of the most important parameters affecting aquaculture water quality. The dissolved oxygen concentration in the aquaculture environment directly impacts growth, survival rates, feed consumption, and digestion. Decreased dissolved oxygen concentration can cause stress for aquaculture species (Tanveer et al., 2018). Several studies explain that dissolved oxygen is related to the hatching rate of fish eggs, growth, low feed consumption, and even mass mortality (Mohan et al., 2022).

Aquatic organisms have different oxygen requirements depending on their types, as cold-water fish require a minimum dissolved oxygen of 6 mg/L, while freshwater and saltwater fish require a minimum dissolved oxygen of 5 mg/L. Most fish species can tolerate a decrease in dissolved oxygen below that minimum threshold for a short period. However, fish mortality can occur if the dissolved oxygen concentration is below 2 mg/L (Mohan et al., 2022).

Some factors influence the need for dissolved oxygen, such as the need for dissolved oxygen for fish growth. Low dissolved oxygen can have side effects on fish growth and even cause death (Sultana et al., 2017). In addition, water quality parameters also affect the need for dissolved oxygen, as stated by Bui et al. (2013) that dissolved oxygen has an inverse relationship with water quality parameters such as temperature, phosphate, nitrite, Total Ammonia Nitrogen (TAN), and Total Organic Matter (TOM), but does not have a relationship with water quality parameters such as pH, CO^{3-2}, HCO^{3-}, and alkalinity, feed consumption, and microorganisms (Mohan et al., 2022).

Another factor is that the level of dissolved oxygen consumption in shrimp ponds increases with the increase in feed input (Mirzaei et al., 2019). Therefore, it has been shown that the very large amounts of feed given more frequently lead to higher levels of dissolved oxygen consumption in the waters (Ullman et al., 2019). Based on biological parameters, dissolved oxygen negatively correlates with Total Vibrio Count (TVC) and Total Bacteria Count (TBC). The increased abundance of bacteria will reduce oxygen availability in the pond because it is used in decomposition (Aldunate et al., 2018).

Therefore, an aeration system is needed to increase the dissolved oxygen concentration to address these factors. Like the use of blower aerators that can enhance the growth and production of tilapia and synchronize other water quality parameters in the pond (Mohan et al., 2022). The use of blower aerators was also conducted in the studies by Naomi et al. (2020); Zahidah et al. (2022), which resulted in dissolved oxygen concentrations >6 mg/L. In the study by Hamdani et al. (2022), venturi aeration technology was applied to the aquaponics system, contributing dissolved oxygen levels of up to 5 mg/L. In addition, the application of different aeration technologies, such as FBs technology, has also been implemented in aquaponics systems, as seen in the studies by Naomi et al. (2020), Putra et al. (2020); Zahidah et al. (2022). Applying the FBs technology increases the dissolved oxygen concentration to 7.06-7.94 mg/L. The application of MNB technology in the aquaponics system was also implemented by Marcelino et al. (2023), which can increase the dissolved oxygen concentration to 9.31 mg/L.

A positive effect can be achieved by implementing aeration technologies such as blowers, venturi, FBs, and MNBs, fulfilling dissolved oxygen needs for aquatic organisms. However, the differences in the application of technology also yield different dissolved oxygen concentration results, such as MNB and FBs producing higher dissolved oxygen concentrations than other aeration technologies. This occurs because MNBs and FBs produce tiny bubbles in the nano and micro range with a diameter of 150-200 nm, which can provide dissolved oxygen under stable conditions and for a long duration (Andinet et al., 2016). According to Tsuge (2015), the smaller diameter and larger surface area of the bubbles can increase the solubility of dissolved oxygen in water.

4. Conclusions

Based on comparisons from several studies, it can be concluded that applying MNB and FBs technologies is more effective in producing water quality suitable for fish farming activities in aquaponic systems. This technology can produce water quality with dissolved oxygen concentrations >7 mg/L, reduce ammonia concentrations to <0.01 mg/L, nitrate to <0.6 mg/L, and phosphate to <0.3 mg/L.

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