Dissolved Gas Infusion

WHITE PAPER

Dissolved Gas Infusion DGI® Technology

FEBRUARY 2024

Demonstration of the Fuel Tech, Inc. DGI® Dissolved Gas Infusion Technology for an Aquaculture Application at a Shrimp Farm

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EXECUTIVE SUMMARY

Two trials were conducted to determine the effects of growing Pacific Whiteleg Shrimp (Litopenaeus Vannamei) using a high stocking density. In the first trial, traditional bubble aeration via venturis was used until the oxygen demand could not be met, and then partial shrimp harvests were completed to help maintain acceptable dissolved oxygen concentrations. In the second trial, an oxygen infusion process was used to provide an average dissolved oxygen concentration of 10.5ppm, unlocking the potential for more of the animals to reach maturity and to maximize the health status.

The two three-month trials were conducted in concrete raceways in an enclosed greenhouse. A recirculation system (RAS) was used to biologically control NH_3 and NO_2^- with partial water exchanges completed as required to control NO_3^-. The initial stocking density in each trial was approximately 21,000 post-larvae (PL) shrimp in a 98m^2 raceway.

In the DGI® trial, excellent survival and growth was achieved and a mean weight of 42g was reached in about 100 days with a survivability of about 50%. In fact, the individual shrimp growth curves show no significant change from the trial in which selective harvesting was required to manage the high biomass loading. High PL stocking combined with reliable dissolved oxygen (DO) dosing dramatically increased total production as compared to the first trial in which early harvesting was required.

Other observations from the trial include no evidence of trimethyl amine odor at harvest, no evidence of oxidation, no evidence of excessively fast metabolism, no evidence of osmotic shock and no evidence of gas bubble disease, suggesting that maintaining dissolved oxygen levels above saturation in low-salinity water without the presence of bubbles, increases the yield while minimizing any detrimental effects of high oxygen levels.

Figure 1: Shrimp farm in Arizona

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INTRODUCTION

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INTRODUCTION

Wild-caught shrimp populations have declined due to overfishing combined with global climate change. At the same time, the demand for shrimp is increasing both domestically and internationally. Today, shrimp demand is met mostly by aquaculture, with Ecuador being the largest producer. Shrimp aquaculture is an important source to help meet the growing demand. According to the Aquaculture Stewardship Council, in 2020 approximately 55% of the global shrimp production, worth 28 billion USD, was farm-raised.

While the wild shrimp can be farmed sustainably, growth is limited by the need to preserve the marine environment. The Monterey Bay Aquarium Seafood Watch does not give any current wild shrimp fisheries its “Best Choice” rating for sustainability, but many farm-raised fisheries, and all domestic Whiteleg shrimp farms have the “Best Choice” rating.

At the Global Shrimp Forum in 2022, new technologies for shrimp farming were discussed, with particular emphasis on the ability of land-based shrimp farms to address recurring problems in traditional shrimp aquaculture. Although land-based aquaculture was described as a developing technology, the ability to include next-generation technologies to minimize disease outbreaks, eliminate antibiotic residues, and resolve the transportation issues were described as potentially interrupting the status-quo.

Royal Caridea, the shrimp farm owner, had developed a novel system to sustainably grow and harvest Pacific Whiteleg shrimp in vertically stacked raceways. Shrimp have been shown to have a tolerance for supersaturated levels of dissolved oxygen. The owner was interested in evaluating the effect of high dissolved oxygen concentrations on shrimp growth, mortality and quality at harvest. In addition, effects of providing infused dissolved oxygen as opposed to air bubbles was a high priority interest.

The Fuel Tech, Inc. DGI® Dissolved Gas Infusion system is capable of infusing process water with dissolved oxygen in a process that is not limited by the typical atmospheric saturation. Having completed a spring growth cycle in their concrete raceway in 2023, the owner and Fuel Tech collaborated to complete the subsequent fall growth cycle using the DGI system to infuse dissolved oxygen at 150% of saturation while meeting the oxygen uptake requirements of the system, including the shrimp, the resident bacteria and any loss to atmosphere that might occur.

DGI Dissolved Gas Infusion for Oxygenation of Water

Aeration of natural waters and wastewaters is essential to the biological and chemical processes that convert contaminants to safe by-products and sustain the environment. As the end goal of aeration is to increase the dissolved oxygen in the water to make it available for biological and chemical processes, the nitrogen concentration in the air is a significant limit to the rate at which aeration can provide dissolved oxygen. In this case a highly pure oxygen source can be used instead.

The efficiency of oxygen transfer from the gas bubbles into dissolved oxygen molecules in the water is dependent on the size of the bubbles and the depth of the water, as once they rise to the water’s surface their oxygen is lost. In fact, if the oxygen remains in bubbles, it is not available for utilization in the aqueous system.

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The DGI system was developed to significantly increase the rate at which dissolved oxygen can be introduced into a water treatment process. The system uses a combination of technologies and scientific principles to accomplish its performance. First, the DGI system uses a proprietary saturator to pre-dissolve (infuse) high purity oxygen into the slip stream at pressure. The DGI system pressurizes both the high purity oxygen and the slip stream as necessary to achieve the oxygenation goals of the application, up to 300psig.

Finally, the DGI system includes unique technology for injecting the pressurized and oxygenated slip stream back into the receiving body of water. As the receiving body of water is at a lower pressure, the DGI effluent is introduced in a way that both rapidly distributes the oxygenated water and that produces only transient bubbles of sufficiently small size to minimize oxygen loss via rise rate to the water surface. The DGI injection system includes multiple zones of injection as needed to optimize distribution and dispersion of the dissolved oxygen in the process stream being treated.

Figure 2 illustrates the DGI system process. Water from the body being treated is drawn into the DGI system via pumps and is pressurized to the desired operating pressure. The pressurized water and pressurized oxygen are introduced into the DGI saturator, which is a patent-pending, high efficiency device optimized for energy efficiency and infusion efficiency. The oxygen-laden water then exits the saturator and flows to the zoned injection.

DGI® TECHNOLOGY AT-A-GLANCE

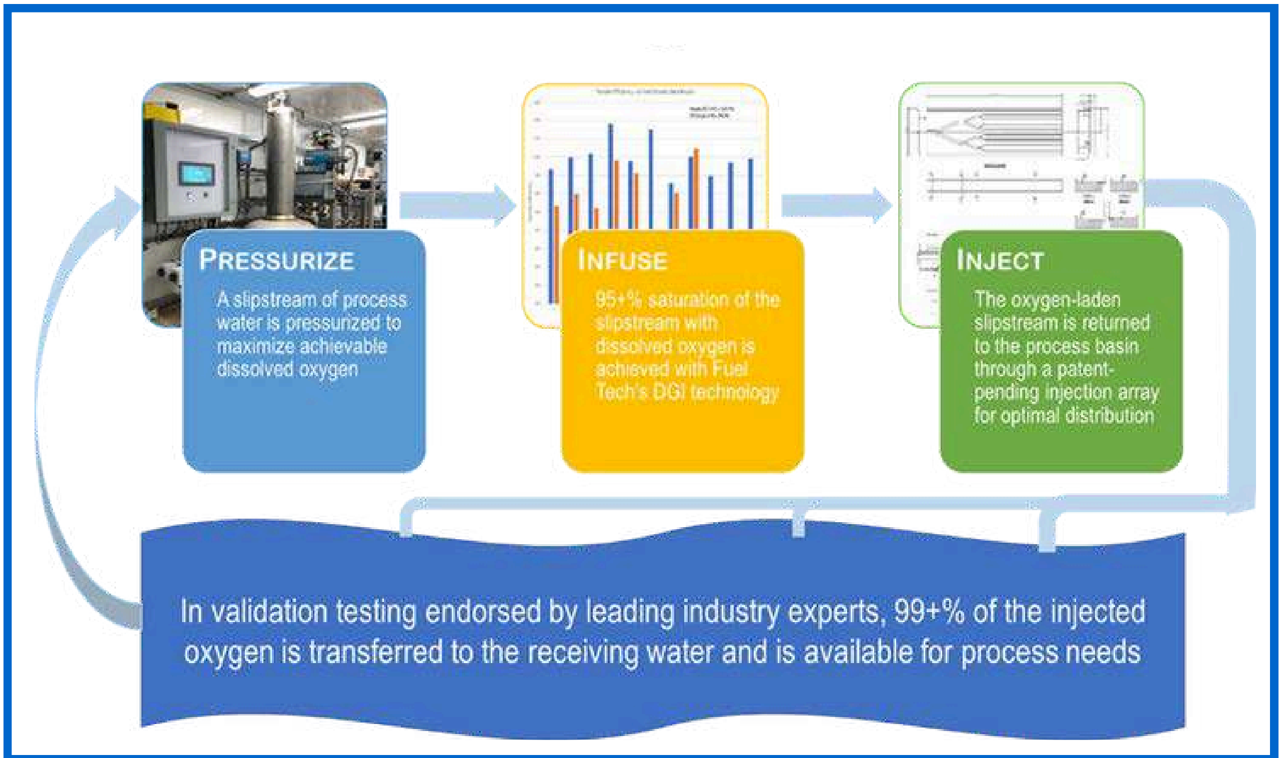

Figure 2: Illustration of the DGI process

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DEMONSTRATION

The two three-month trials (100 day nominal maturation) were conducted in a greenhouse-enclosed concrete raceway with a bottom area of 97.9m^2 and an average water depth of 57cm, see Figure 3. The water was held at about 30°C, with a salinity of about 13ppt. A recirculation system (RAS) was used to biologically control NH_3 and NO_2- and partial water exchanges were completed as required to control NO_3-. The initial stocking was approximately 21,000 PL shrimp in each case, with an estimated 25% loss on planting for an expected 15,750 live animals on Day 1.

In the first trial, traditional bubble aeration via venturis was used to achieve about 7mg/L DO until the oxygen demand could not be met. When the dissolved oxygen (DO) dropped dangerously low, approaching 2mg/L, partial shrimp harvests were completed to help maintain acceptable dissolved oxygen concentrations. The farm staff reported an increase in shrimp mortality.

Figure 3: Concrete raceway covered during operation

DGI Dissolved Gas Infusion Growth Cycle

In the second trial, the Fuel Tech, DGI® process was used to provide raceway dissolved oxygen concentrations at 150% of atmospheric saturation. In this case, the saturation in 30°C water with dissolved marine salts was about 7mg/L, so the system was set to target between 9.5mg/L and 11.5mg/L for an average of 10.5mg/L.

The DGI system was available on a portable skid, see Figure 4, that was installed in a protected space just beside the greenhouse. A small slipstream of water from the raceway circulation system was sent to the DGI filtering module and skid where it was infused with high-purity oxygen.

The resulting stream of infused raceway water was sent through two injector lines to two locations on opposite sides of the raceway to provide balanced oxygenation. Two DO probes were also installed in the raceway, just upstream of each injection point to insure a well-diffused DO measurement and control signal. The PLs were introduced to the raceway on July 2, 2023, the venturi air inlets were sealed and the DGI skid provided DO to the raceway for the subsequent 101 days of the demonstration.

Figure 4: DGI skid

In the DGI® trial, excellent survival and growth was achieved and a mean weight of 42g was reached in about 100 days with a survivability of about 50%. In fact, the individual shrimp growth curves, as reported by the owner, show no significant change from the trial in which selective harvesting was required, see Figure 5.

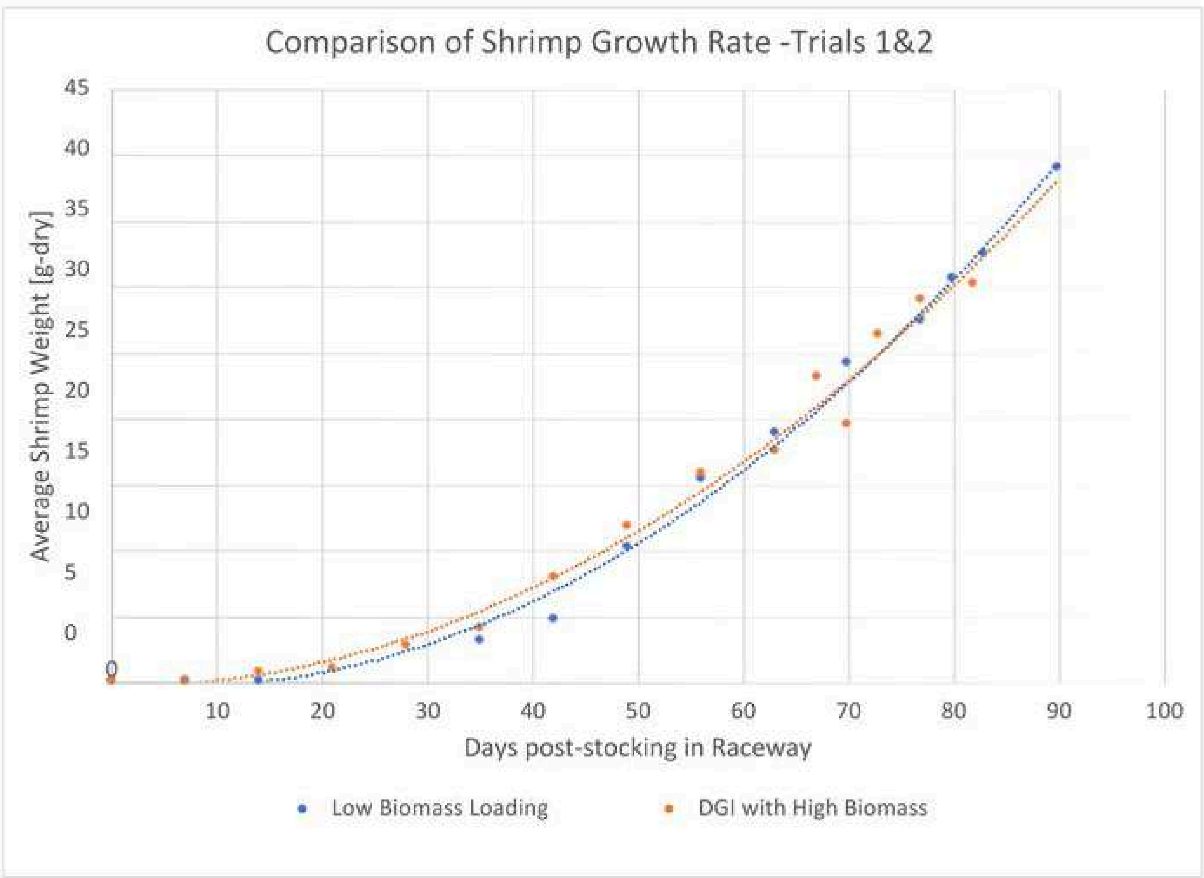

Figure 5: Shrimp growth rate

The oxygen demand of the system was relatively low in the early part of the demonstration. The average oxygen demand during the first five days was less than 0.7 pounds per day. Although there was some small oxygen demand by the PLs and any bacteria in the water, 0.7 lbs/day will serve as a maximum assumption for oxygen lost to the atmosphere through the water surface. As the dissolved oxygen (DO) was consistently above the atmospheric saturation of 7mg/L, some small loss is expected even though the DGI injectors are specifically designed to minimize mixing in the vertical water column.

The oxygen demand (and corresponding process water flow) is shown for the entirety of the demonstration period in Figure 6. The oxygen demand was affected by the quantity and size of the shrimp, the bacterial activity in the raceway, several water replacements to control nitrate concentrations and a few early harvests of shrimp for marketing and business development purposes.

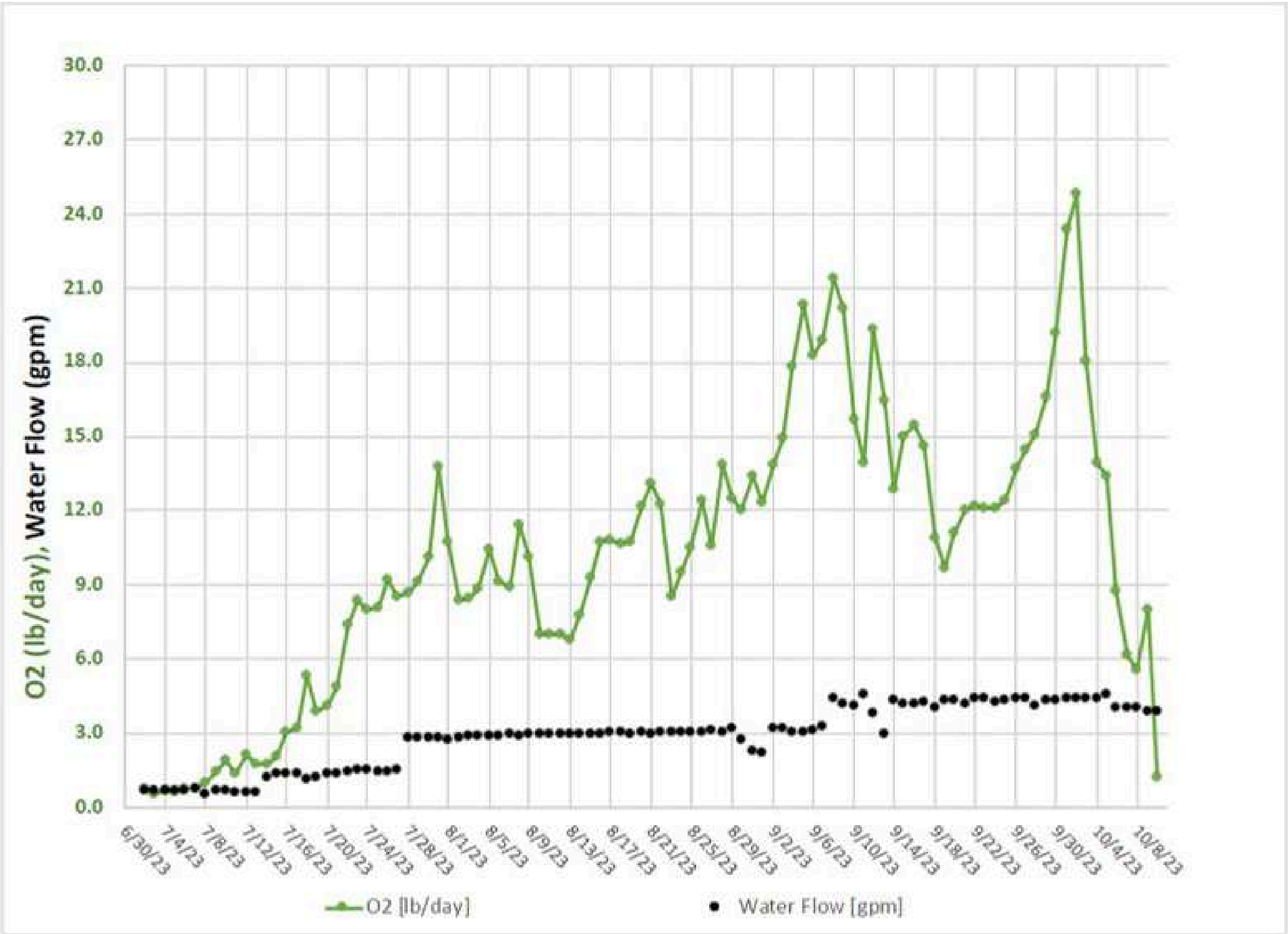

Figure 6: Oxygen & process water flow through the DGI

As expected, the demand for dissolved oxygen increased as the shrimp grew, and the DGI system utilized more process water. The water varied from about 0.7gpm in the early stages to 4.5gpm in the final weeks of the growth cycle. All this water came from the raceway and was returned to the raceway.

Looking in detail at the near-linear portion of the shrimp growth and the elective harvests in the final weeks, it is possible to estimate the shrimp biomass loading throughout the demonstration period. This is shown in Figure 7.

The plotted data show an average growth rate of 3.8 grams per week, shown by the line fitted to the blue circles. The biomass loading is expected to increase with shrimp weight, decrease due to some small shrimp mortality that is typical, and obviously decrease when elective harvests decrease the population of shrimp in the raceway. Each of the green vertical lines indicates a partial harvest and the red dots show the calculated biomass loading. Prior to the first harvest, the biomass loading peaked at 2.4 kg/m^2.

It can be inferred from this plot that the biomass loading, in the absence of any elective harvesting, would have reached about 4.0 kg/m^2 by the final day of the cycle.

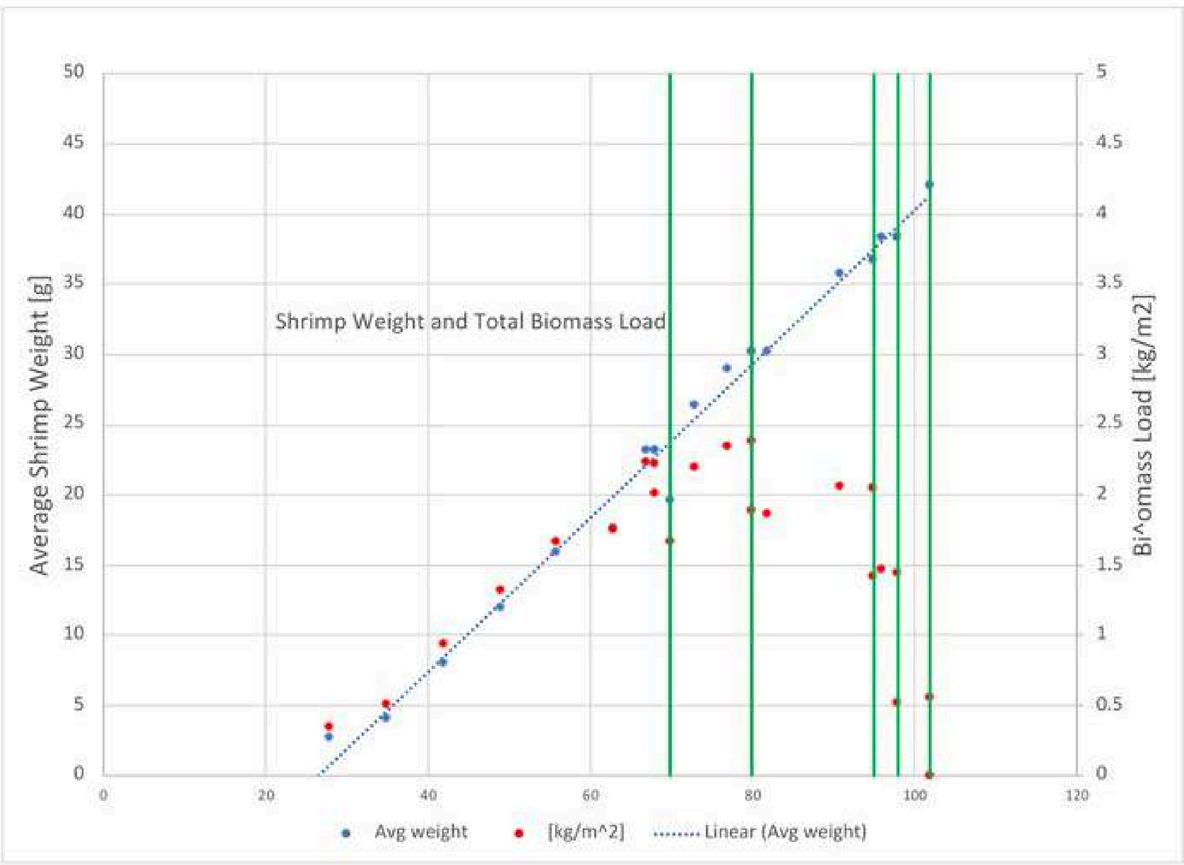

Figure 7: Biomass load

Looking more closely at the data, Figure 8 shows the DO trend in the raceway on Day 30, when the shrimp averaged about 3g, and the total biomass loading was only 0.35kg/m^2. The DO was consistently held between 9.5mg/L and 11.5mg/L and required about 14 cycles of infusion throughout the day.

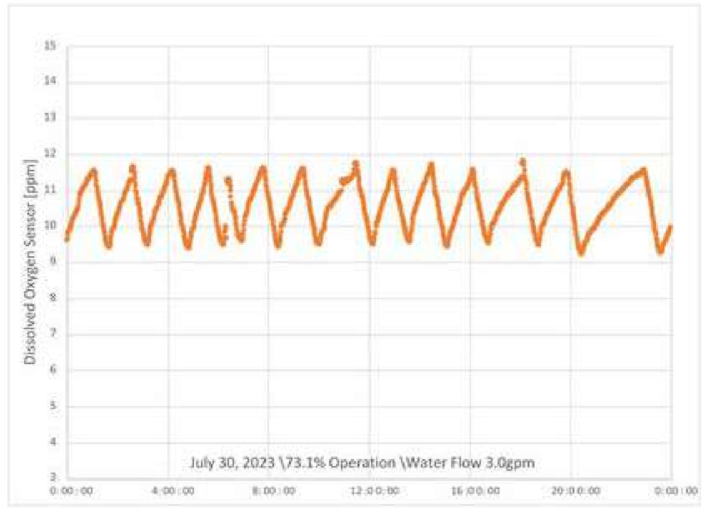

Figure 8: Dissolved oxygen control trend for Day 30

In contrast, Figure 9 is a similar plot for Day 79. The shrimp average weight was about 30g, and the total biomass loading was 2.4 kg/m^2. The DO was still held reliably between 9.5mg/L and 11.5mg/L but required more water and 26 cycles of infusion. It would also be possible to tune the DGI system to deliver dissolved oxygen more slowly and attempt to match the rate at which the oxygen is being depleted, but as the DGI system is designed to react rapidly to demand, both strategies achieve the same desired outcome.

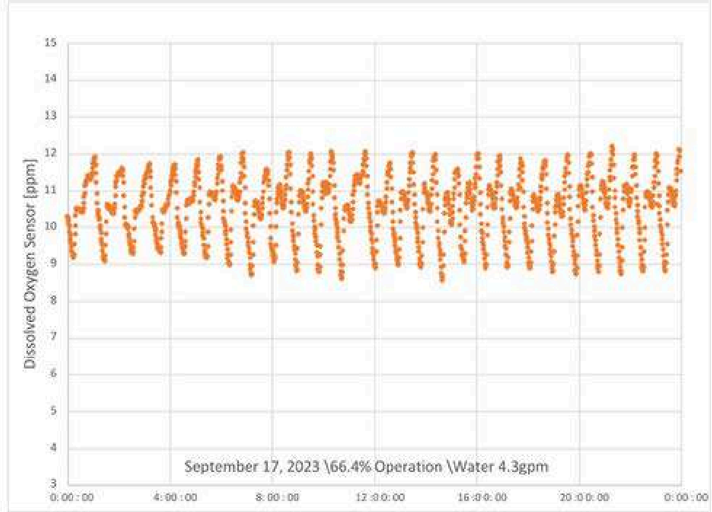

Figure 9: Dissolved oxygen control trend for Day 79

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FINAL SUMMARY

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FINAL SUMMARY

Working together, Fuel Tech and the shrimp farm owner successfully tested the DGI® process in this shrimp raceway application. The DGI system operated reliably using advanced computer controls, remote monitoring, and data acquisition systems. The DGI was able to maintain consistent dissolved oxygen (DO) concentrations 50% higher than atmospheric saturation levels, with very little loss of oxygen to the atmosphere and no mortality associated with low-DO events. The system provided anywhere from one pound of oxygen per day to 24 lbs/day, depending on the demand of the shrimp in each phase of production.

Other observations from the trial include no evidence of trimethyl amine odor at harvest, no evidence of oxidation, no evidence of excessively fast metabolism, no evidence of osmotic shock and no evidence of gas bubble disease. This suggests that maintaining dissolved oxygen levels above saturation in low-salinity water without the presence of bubbles, increases the yield while minimizing any detrimental effects of high oxygen levels. Figure 10 shows the shrimp, some more than 55g, at the final harvest.

Figure10: Sample of shrimp at harvest

High PL stocking and reliable DO dosing with automatic controls dramatically increased total production capability as compared to the first trial using induced-air though water venturis. This unlocks future development in raceway design and DGI system controls to support a fully automated process that can provide fresh, never frozen, shrimp to any location.

The DGI system has now been shown to be effective in land-based aquaculture. DGI has previously been proven effective and efficient in delivering targeted dissolved oxygen infusion in a detailed and peer-reviewed lab study, in wastewater aeration basins, as well as municipal and industrial wastewater settings.

Technologies for clean air & pure water

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Fuel Tech develops and commercializes state-of-the-art proprietary technologies for air pollution control, process optimization, water treatment, and advanced engineering services. These technologies enable customers to operate in a cost-effective and environmentally sustainable manner. Fuel Tech is a leader in nitrogen oxide (NOx) reduction and particulate control technologies and its solutions have been in installed on over 1,300 utility, industrial and municipal units worldwide.

The Company's FUEL CHEM® technology improves the efficiency, reliability, fuel flexibility, boiler heat rate, and environmental status of combustion units by controlling slagging, fouling, corrosion and opacity. Water treatment technologies include DGI® Dissolved Gas Infusion Systems which utilize a patented channel injector to deliver supersaturated oxygen solutions and other gas-water combinations to target process applications or environmental issues. This infusion process has a variety of applications in the water and wastewater industries, including remediation, aeration, biological treatment and wastewater odor management. Many of Fuel Tech's products and services rely heavily on the Company's exceptional Computational Fluid Dynamics modeling capabilities, which are enhanced by internally developed, high-end visualization software.