Comparing the Velocity Flow Rates of Four Aeration Diffusers

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Abstract:

Introducing diffused aeration into a body of water is an effective way to incorporate oxygen and encourage water mixing. This is done by using compressed air to lift bottom water to the surface. In this study four different diffusers (the ECO diffuser, 2x 23cm Rubber Disk diffuser, 4 U-Shaped Tube diffuser, and SS- diffuser) were tested against one another to determine which diffuser produces the highest average flow rate (gallons/min). Average flow rate was determined by measuring water velocity and multiplying it by the area of water movement produced by each diffuser (Q=A*V). Ultimately, this study finds that all diffusers produce higher flow rates at higher CFMs (1.5 CFM vs. 2.5 CFM). Data also shows that the SS diffuser produces the greatest average flow rate in comparison to the other tested diffusers. All diffusers were tested in a natural outdoor setting at a depth of 3.2 m to simulate real- world diffuser applications.

Introduction:

Aquatic systems are sensitive to change and external inputs, such as nutrients. Therefore, water composition and quality can be easily altered resulting in bad odours, murky water, algae growth, and fish kills. Diffused aeration is a simple and effective method that uses waters own physical properties to help maintain equilibrium in water systems and improve overall water quality.

Diffused aeration is the process of incorporating compressed air into an aquatic system. This is done by forcing air through a diffuser surface to lift oxygen depleted bottom water to the surface and produce air bubbles in the water. These air bubble quickly rise to the surface to induce oxygen transfer and encourage water movement. Aeration has been proven to reduce or eliminate sludge and algae in aquatic systems across North America and improve overall water quality.

Ultimately aeration efficiency can vary. Efficiency is dependent upon diffuser depth, air supplied (CFM), and diffuser design. This paper aims to investigate the effectiveness of four popular diffusers for moving water (ECO diffuser, 2x 23cm Rubber Disk diffuser, 4 U-Shaped Tube diffuser, and SS- diffuser). The SS and ECO diffuser use Pond Pro's own Pond Pro Fine Bubble Airline® which is a uniquely porous airline that produces curtains of very fine bubbles. This design ensures the formation of equally sized micro-bubbles which rise and disperse over a much great surface area, in comparison to coarse bubbles. The 4 U-shaped tube diffuser uses a similar porous airline to also produce curtains of fine bubbles. The Rubber disk diffuser uses two disks (23 cm in diameter) as its diffuser surface. This diffuser produces more coarse bubbles in two concentrated areas. Ultimately, the objective of this study was to determine the average flow rates for each diffuser at 1.5 and 2.5 CFM, when submerged 3.2 m.

Testing location:

Diffuser testing was conducted over a 5-day period in a natural, outdoor 1829.11 m^2 pond in November of 2020. The average water temperature recorded over the span of the testing period was 1.9 °C throughout the pond. Constant aeration of the testing pond prior to diffuser testing ensured constant through-temperature and an ice-free surface. The pond has a maximum depth of 3.90 meters.

Testing set-up:

To test the diffusers a floating 4.9m x 4.9 m dock was placed in the center of the pond (Fig 1). The dock was constructed to have an open 13.4 m^2 area in the center of dock to allow for controlled submersion of the diffusers, depth manipulation, and accurate water velocity readings. A cable was stretched over the center of the inner diameter of the dock with a 100 cm rod attached to a Hach FH950 Portable velocity meter. The velocity probe was fully submerged (0.6 m below the surface) and took three velocity readings, with ten second intervals. The cable was marked with 15 cm markings allowing us to accurately move the probe in 15 cm increments over the diffuser until a minimal (< 1.0 cm/s) velocity was recorded.

Figure 1. Diffuser testing location and set-up.

All diffusers were connected to a ½ HP compressor (KM 120C) using ½" sinking line. Compressor air supply was controlled using an acrylic flow meter. Diffusers were lowered to max depth using ropes attached to the corners of the dock to ensure proper orientation of the diffuser. The SS diffuser is symmetrical in shape; thus, orientation does not affect average flow rate. The ECO, 2x 23cm Rubber Disk, 4 U-Shaped Tube, area irregularly shaped (eclipse). Oval shaped plumes were noted during testing. To account for the oval shape, all diffusers were tested in parallel and perpendicular orientation relative to the cable. All diffusers were tested at maximum depth (d= 3.2 m)

Results:

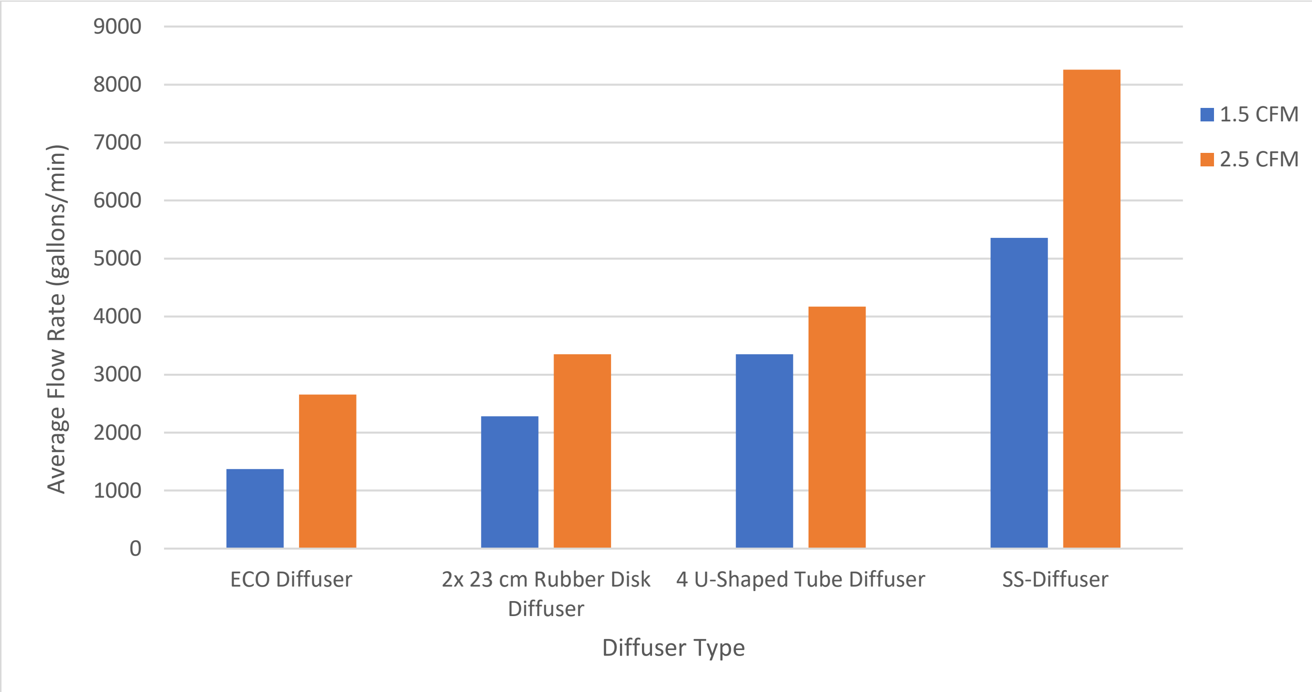

Figure 2. Average flow rates (gallons per minute) of four different diffusers at different CFMs. Average flow rates were measured at a depth of 3.30 m.

Our results show that the SS-diffuser has the highest average flow rates at both 1.5 and 2.5 CFM (Q_{SS}= 5358.7gallons/min and 8257.9 gallons/min respectively) (Fig. 3). The 4 U-Shaped Tube diffuser shows an average flow rate of 3348.1 gallons/min at 1.5 CFM, and 4174.4 gallons/min at 2.5 CFM. Data shows that the comparable 2x 23cm Rubber Disk diffuser has a lower average flow rate than the 4 U-Shaped Tube diffuser at 1.5 and 2.5 CFM (Q_{RD}= 2282 gallons/min and 3349.4 gallons/min, respectively. The ECO diffuser shows the lowest average flow rate among all tested diffusers at both 1.5 and 2.5 CFM (Q_{ECO}= 1373.4 gallons/min and 2654.4 gallons/min respectively).

Our testing method allows us to determine maximum diameter of water flow produced 0.6 m below the water surface for each diffuser. The SS- Diffuser produces a 210 cm diameter at 2.5 CFM, while the ECO diffuser produces a 150 cm diameter of water flow at 2.5 CFM. The

2x 23cm Rubber Disk and 4 U-Shaped Tube diffusers clearly produce oval shaped areas of water movement, due to the asymmetry of the diffuser. Therefore, the 2x 23cm Rubber Disk produces a major axis of 180 cm, while the 4 U-Shaped Tube produces a 210 cm major axis at 2.5 CFM.

Discussion:

Diffusers effectively incorporate air into water by forcing compressed air through the system. This process results in the lifting action of water from the bottom of a pond to the surface. This lifting process can be measured in terms of how quickly water rises from the diffuser to the top in order to determine the average flow rates for each diffuser at specific CFMs. In this study we determined the average flow rates (gallons/min) for each tested diffuser. Average flow rates were calculated by flow rate equaling average velocity multiplied by area (i.e. Q=A*V; where , Q= flow rate (cm^3/s), $A_{A,B,C,D,E}$= area (cm^2) and V= average velocity (cm/s)) (Fig 3)

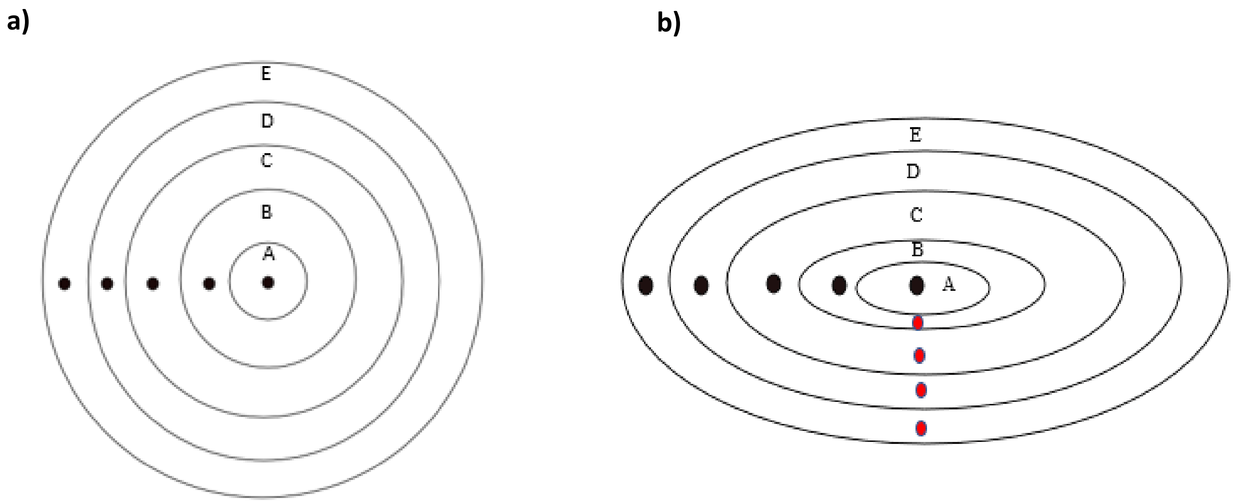

Figure 3. Diagram showing how average flow rate for diffusers were determined, based on bubble plumes produced. Black dots represent 15 cm increments of where vertical velocity measurements were taken with a Hach FH950 flow meter. Letter A-E represent the areas calculated. A) represents circular bubble plume areas produced. B) represents oval plume areas produced for asymmetrical diffusers. The red dots represent vertical velocities taken when diffusers are oriented perpendicularly across the cable to get minor axis length. Note, diagrams are not to scale.

By calculating flow rate as a product of area and velocity we can account for the average flow rate (gallons/min) over the entire area of produced vertical flow, rather than reporting maximum flow. The SS- diffuser's symmetrical design produces a large circular plume at the surface (Fig 3a). The other tested diffusers are asymmetrical in shape and clearly produce oval plumes at the surface. To calculate flow, the area of an ellipse was calculated (Fig 3b). This was done by changing the orientation of the diffusers to be parallel with cable and perpendicular to the cable and averaging the velocities. By calculating flow as the product of velocities in each area is more accurate and applicable to real-world scenarios where aeration is required. This study focuses on the average flow rates produced by different diffusers at standardized CFMs (1.5 and 2.5), while at a maximum depth of 3.2 m. Overall, flow rate is influenced by multiple factors including, diffuser depth, supplied air (CFM), and diffuser area (cm^2).

Diffuser submergence depth greatly influences flow rate (Ashley et al. 2009). Studies have found that the deeper a diffuser is placed, the more flow it will produce. This is because water and air are pushed a greater vertical distance; therefore, resulting in a wider plume produced. Our data is representative of a depth at 3.2 m. We expect each diffuser to have a greater flow output at greater depths.

The amount of air supplied to the diffuser is directly related to its output. Since diffused aeration rely on compressed air to lift water from the bottom of a body of water to the surface, higher CFMs will directly result in higher flow rates. This is exemplified in our data (Fig 2). All diffusers tested have a higher average flow at 2.5 CFM compared to 1.5 CFM.

The amount of CFM supplied also influences average flow by increasing bubble production. Computational fluid dynamics (CFD) modeling has shown that air bubbles have a higher velocity than water (Thijssen et al. 2019). Large bubbles have especially high velocities compared to smaller bubbles. In this study, velocities were measured using a Hach FH950 flow meter. This probe acts as a limitation to this study as it does not discriminate between air and water velocity. It was observed that the diffusers using porous airline produced many micro-bubbles while the disk diffuser produced larger bubbles. From this observation we can infer that our velocity data has an approximate 15% margin of error, while that margin of error would be slightly higher for the disk diffuser due to producing larger bubbles. Despite having a margin of error, results in this study are relative since all diffusers were tested using the same meter.

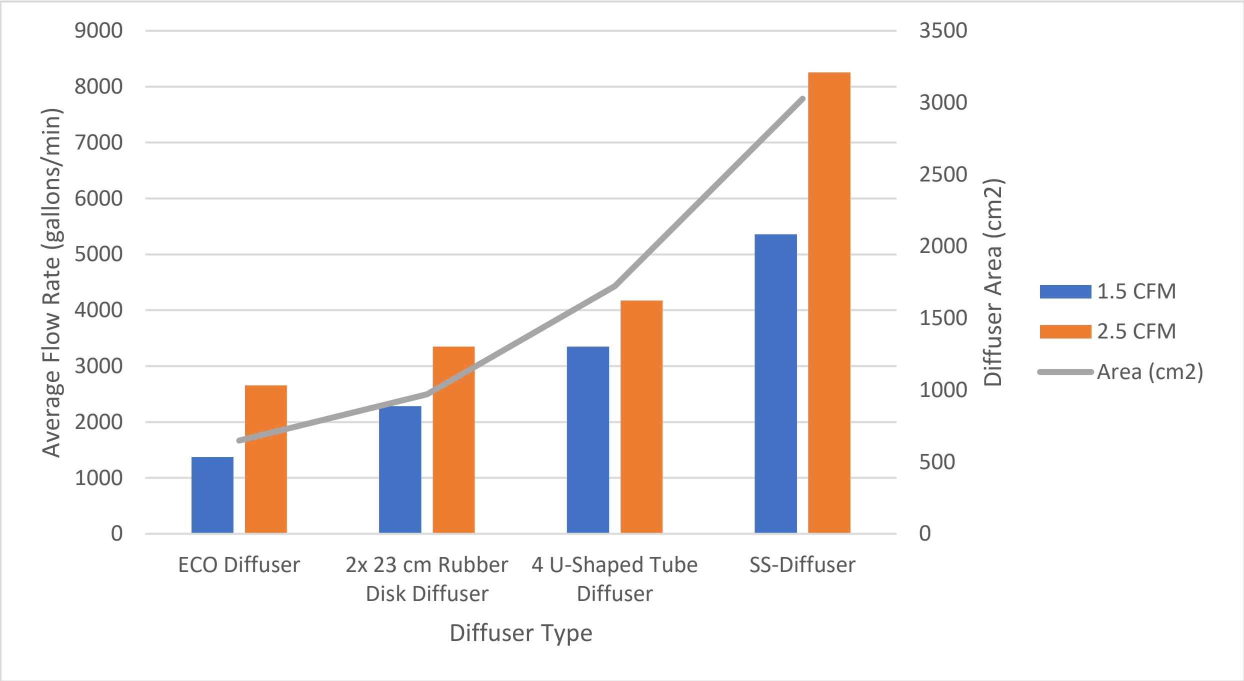

Figure 4. Average flow rates (gallons per minute) of four different sized (cm^2) diffusers at varying CFMs. Average flow rates were measured at a depth of 3.30 m.

In addition to depth and air supply, average flow rate is influenced by diffuser design. The four tested diffusers varied greatly in size ($Area_{ECO}$= 648.6 cm^2, $Area_{Rubber\ disk}$= 969.9 cm^2, $Area_{U\text{-}Shaped}$= 1724.5 cm^2, and $Area_{SS}$= 3027.5 cm^2). Diffuser surface area has been shown to relate to average flow output. Our data shows that diffusers with larger surface areas will produce greater flow at both 1.5 and 2.5 CFM (Fig 4). This relationship between diffuser area and flow rate explains why the SS significantly outperformed the other three diffusers. Larger diffuser area will produce a larger area of water movement, to consequently generate a higher average flow. More area can also support greater airflow. Although our data shows that average flow increases with increasing diffuser area, it must be noted that this is a defined relationship. Average flow rate is influenced by several factors that work together to affect diffuser efficiency. Ultimately, more data would need to be collected in order to determine the minimum, maximum and optimal airflow per cm^2 to produce the most efficient flow rate (gallons/min).

Nonetheless, the results in this study conclusively show that the SS- diffuser has the highest average flow rate when tested against three other diffusers. Limitations must always be accounted for in any study, therefore, we must address several in this study. As discussed, the FH950 probe acted as a limitation due to its inability to discriminate between air and water velocity. In addition to this, probe accuracy acts as another limitation to this study. Hach 2018 reports that the FH950 meter relies on an electromagnetic sensor to detect water velocity with a ± 2% reading accuracy. Proper calibration was ensured before use; however, electromagnetic sensors are less sensitive to low velocities. Due to limited accuracy of this probe, a more sensitive probe would be able to more accurately define velocities produced by the diffusers at greater distances away from the center of the plume, to show the true area produced. Environmental parameters account for more limitations. Winds create surface waves which can penetrate approximately half its wavelength below the water surface to create some turbulence. The probe was place 60 cm below the surface, so it is possible that wind influenced velocity readings. Slight winds were present during testing.

Conclusion:

This study was designed to determine the average flow rates of four different diffusers (ECO diffuser,2x 23cm Rubber Disk diffuser, 4 U-Shaped Tube diffuser, and SS- diffuser). By understanding how much flow a diffuser produces can help us determine how much aeration is needed for certain applications and pond needs. This study was conducted in a natural outdoor setting to mimic real-world conditions, allowing us to more accurately show each diffuser's true performance at a depth of 3.2 m.

Overall, our results show that all four tested diffusers successfully move water at 1.5 CFM and 2.5 CFM; however, the SS- diffuser produced the highest average flow rate (gallons/min) overall (Fig 2). These results are attributed to its unique design allowing it to have a large surface area. More diffuser area will move more water per CFM. Overall, our results show that a relationship between diffuser area and flow rate exits. This relationship may be used in future studies to conclusively predict optimal CFM for each diffuser in order to maximize flow rate efficiency.

Limitations including probe accuracy and environmental parameters do affect the accuracy of this data, thus, data is relative but not absolute. Future studies are planned in a more controlled environment to minimize errors and to look at diffuser flow rates at different depths.

References:

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