CFD Simulation on Improving Water Quality based on Various Aerator Models to Demonstrate Cost Performance Analysis

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Abstract. There are many types of aerator that can be used to perform a water treatment process either from air to water or from water to air approaches. Other than focusing on the performance itself, the usage cost of aerator should be forecasted in detail too to have a sustainable and economical method in remediating the polluted water. Therein, the cost performance analysis was demonstrated by performing a computational fluid dynamics (CFD) simulation on improving water quality based on various aerator models. The simulation was focused in a small-scale aeration tank that consists of a mixing chamber, air duct, and a few of bubble diffusers. The improvement of water quality was assessed by calculating the number of gas bubble particles produced by 4 different configurations of aerator model, namely aerator model A, B, C and D, respectively. Results found that the aerator model D (5 bubble diffuser at 620 L/min) produces the highest number of gas particles up to 72.2%. However, the aerator model C (5 bubble diffuser at 300 L/min) was found to achieve the most efficient and sustainable approach based on energy consuming and cost of aerator configuration when compared to the other aerator models.

1. Introduction
Dissolved oxygen (DO) is defined as the amount of free oxygen present in the water. Excessive or inadequate DO content can harm aquatic life and affect the water quality [1–2]. To solve this problem, water aeration is introduced to increase or maintain the oxygen saturation of water either in natural (river, lake) or artificial (pond, aquarium) environments. This solution brings water and air into close contact (in the means of circulating, mixing or dissolving oxygen) by introducing air bubbles and allowing them to rise through the water [3]. As a major water treatment process, certain constituents in the water will be removed (such as carbon dioxide) or modified (such as iron, hydrogen sulphide, and volatile organic chemicals) [4].
The aeration’s efficiency depends on the amount of surface interaction between air and water, which is mainly influenced by the size of the water drop or air bubble (fine/coarse). The efficiency of oxygen transfer rate also depends on the flow rate or type of the aerator used [5–6]. Other than considering solely on the performance of aerator, the total cost of aerator usage should be considered as well since different scenarios require different types of aerator. Hence, this study was carried out to demonstrate the cost performance analysis by performing computational fluid dynamics (CFD) simulation, specifically on the number of gas bubble particles produced under different aerator models in the designated aeration tank. The gas bubble particles’ velocity as well as the kinetic movement between gas bubble particles and fluid phase were also discussed in this paper.

2. CFD simulation

2.1 Aerator model
The simulation of the aeration system in this study was focused on a small-scale aeration tank with a fluid region’s volume of 84.0 m³, i.e., 4.0 m depth of water and 21.0 m² of tank’s area. The studied volume of fluid region was set based on the estimation size of a small pond/artificial river. Figure 1 illustrates the aerator model that consists of a mixing chamber, an air duct, and a number of bubble diffusers. To simulate the aeration process, the air from the outer environment is channelled into the mixing chamber through the air duct. Then, the air was released from the bottom of the tank through the bubble diffuser and start to mix with the water molecules.

![Diagram of aeration tank.](image)

**Figure 1.** Design of aeration tank.

2.2 Boundary condition
Several realistic boundary conditions were set in this study to simulate the aeration process at various aerator models. For instance, the simulation was conducted by considering the properties of river water at Malaysia during dry season only as tabulated in table 1. Besides, the simulation process was limited up to 200 seconds by using 2 different flow rates of air blower (gas bubble particle’s source) which are 300 L/min and 620 L/min, respectively.

| Properties             | Values  | Properties             | Values  |
|------------------------|---------|------------------------|---------|
| Temperature (°C)       | 26.035  | Kinematic viscosity (m²/s) | 1.002 × 10⁻³ |
| Density (kg/m³)        | 998.21  | Hydrostatic pressure (MPa) | 3.295 × 10⁻³ |
3. Results and discussion

3.1 Gas bubble particles’ velocity

Figure 2 depicts the gas bubble particles visualization of 2 different aerator models. The contour of aerator model B (620 L/min) was observed to have a higher velocity of gas bubble particles compared to aerator model A (300 L/min). The velocity was observed to keep rising until it reached the maximum reading at $t = 8$ s. After that, a constant reading of velocity was observed until the end of simulation due to the limited hydrostatic pressure inside the enclosed aeration tank.

![Figure 2](image)

FIGURE 2. Gas bubble particles’ velocity visualization comparison between aerator model A and B.

Table 2 compares the maximum and average velocities of gas bubble particles under different aerator models. Both aerator models presented a small range of velocity but in general, the kinetic movement particle motions may influence the velocity of the gas bubble particles. It indicates that there is an inelastic collision between the local particles, considering the particle rotation, increment of energy transfer, and dissipation inside the region [7].

| Parameters                  | Aerator model A | Aerator model B |
|-----------------------------|-----------------|-----------------|
| Flow rate (L/min)           | 300             | 620             |
| Maximum velocity, $V_{max}$ (m/s) | 0.679           | 0.811           |
| Average velocity, $V_{average}$ (m/s) | 0.478           | 0.622           |

3.2 Kinetic movement between gas bubble particles and fluid phase

Figure 3 portrays the kinetic dissipation of gas bubble particles and fluid region of 2 different aerator models. The liquid phase eventually impinges on the right-side wall, and the liquid flow rapidly forms a jet upwards. The diffusion of gas bubble particles with the fluid phase during this time is almost dependent on the kinetic movement of gas bubble particles through bubbles formation.
The gas bubble particles supplied in both aerator models had reached the maximum upward elevation inside the aeration tank after running simulation \( t = 26 \) s. A constant interaction movement between fluid phase and gas bubble particles was observed after \( t = 66 \) s for both aerator models until the end of simulation. Results show that the aerator model B exhibits faster gas diffusion compared to aerator model A.

![Image](a) Aerator model A (b) Aerator model B

**Figure 3.** Kinetic dissipation of gas bubble particles and fluid region comparison between aerator model A and B.

### 3.3 Number of gas bubble particles produced

Figure 4 shows the simulated number of gas bubble particles produced by various aerator models. The results obtained are based on the mass transfer properties of gas-induced pulsed flow and the continuous gas flow conditions. The aerators model A and B were simulated with 3 bubble diffusers, while the aerator models C and D were simulated with 5 bubble diffusers.

![Image](Number of gas bubble particles produced by various aerator models.)

**Figure 4.** Number of gas bubble particles produced by various aerator models.
The aerator model A in this study was set as a reference model to implement an aeration system in a river. In comparison, the aerator model B produces a higher amount of gas bubble particles than the aerator model A. Nevertheless, the total number of gas bubble particles by aerator model B shows an improvement of 46.4% only compared to the aerator model A even the flow rate performance was enhanced by 106.7%. Further simulations were performed by using 5 bubble diffusers at different flow rates (aerators model C and D).

Simulation results show that the aerator model C produces more total gas bubble particles up to 67.9% when compared to the aerator model A. This finding proves that more gas bubble particles can be produced by adding more bubble diffuser. In case of the aerator model D, the gas bubble particles managed to increase up to 72.2%, which is a slightly higher than the aerator model C. This can be attributed by the limited distribution of the gas bubble particles, which depends mostly on the size of the aerator tank. Thus, for this tested volume of aeration tank (84 m$^3$), the maximum number of bubble diffuser was studied up to 5 bubble diffusers.

3.4 Cost performance analysis

The cost performance analysis were performed by evaluating on 2 main results. First, the gas bubble particles distribution based on maximum and average values by various aerator models as revealed in figure 5. Second, the estimated cost distribution of each aerator model as revealed in figure 6. Based on the results, the aerator model C was selected as the most efficient aerator configuration. This model is an improvised model of the aerator model A, which the bubble diffuser is added up to 5 and the flow rate performance is fixed at 300 L/min.

A more effective approach to improve the total gas bubble particles in the aerator tank was proven by increasing the number of bubble diffuser instead of increasing the air flow rate performance as shown by the results of aerator model B. The high velocity and kinetic movement of gas particles originated from the flow rate of air blower do no significantly improved the total gas bubble particles. Yet, this approach will expand more cost on purchasing high performance of air blower and on the annual electric bills. This statement can be supported by referring to table 3. Based on the Cost$_{total}$ and the $\left(\frac{\text{GBP}}{\text{m}^3}\right)$, the aerator model C achieves the highest of $\left(\frac{\text{GBP}_{\text{total}}}{\text{RM} \cdot \text{m}^3}\right)$, which is 1,075,056 compared to the other aerator models.

![Figure 5. Gas bubble particles distribution based on maximum and average values by various aerator models.](image-url)
Figure 6. Estimated cost distribution based on various aerator models.

Table 3. Cost per cubic meter of gas bubble particles improvement by various aerator models.

| Descriptions                                      | A    | B    | C    | D    |
|--------------------------------------------------|------|------|------|------|
| Total cost involved, Cost_{total} (RM)           | RM 587.06 | RM 774.52 | RM 617.06 | RM 637.06 |
| Total gas bubble particles distribution per cubic meter, \(\frac{\text{GBPd}_{\text{total}}}{\text{m}^3}\) | 378,520,971 | 554,255,871 | 663,374,443 | 683,801,729 |
| Total gas bubble particles distribution in cubic meter per unit ringgit, \(\frac{\text{GBPd}_{\text{total}}}{\text{RM} \cdot \text{m}^3}\) | 644,773 | 715,612 | 1,075,056 | 1,073,371 |

4. Conclusion
The cost performance analysis of various aerator models had been demonstrated by performing CFD simulations on water quality improvement in a small-scale aeration tank. The water quality improvement was evaluated in duration of 200 s by calculating the total gas bubble particles produced under a different number of bubble diffuser and different flow rate of air blower (primary gas bubble particles’ source). Based on the simulation results, the air blower with a higher flow rate produces more gas bubble particles compared to a lower flow rate of air blower (aerator model B). But, more gas bubble particles can be obtained by adding more bubble diffuser at a lower flow rate of air blower in the aeration tank (aerator model C). For this study, although more gas bubble particles can be produced with a higher flow rate of air blower and a high number of bubble diffuser (aerator model D), the overall gas bubble particles diffused into the water is not efficient since high power and more cost are required to operate the aeration process. The aerator configuration, specifically the part which air is supplied into the water (fluid region) from the bottom of the aeration tank is recommended to be focused in order to enhance the gas bubble
particles distribution. Nonetheless, the limitation size of aeration tank/static artificial river/pond should be considered in the future simulations or experimental studies.

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