Development of a Novel Aeration Measurement System to Evaluate Water Treatment Process in a River

M F H Rani1,2, N S Kamarrudin1,2, A B Shahriman1,2, Z M Razlan1,2, K Wan1,2, M S M Hashim1,2, I Ibrahim1,2, A Rahman1,2, Z Ibrahim3, M K Faizi1,2, M A S M Hassan1, 2, A A Abd Manap4 and I F Zainuddin4

1Faculty of Mechanical Engineering Technology, Pauh Putra Campus, Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia.
2Centre of Excellence Automotive & Motorsports (MoTECH), Pauh Putra Campus, Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia.
3Department of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Brunei, Jalan TunTK Link, Mukim Gadong A, BE1410 Brunei Darussalam.
4Department of Irrigation and Drainage Perlis, JPS Perlis Complex, Pengkalan Asam, 01000 Kangar, Perlis, Malaysia.

Email: faizhilmi@studentmail.unimap.edu.my

Abstract. A novel aeration measurement system was developed to evaluate the water treatment process in a river to acquire a more comparable dissolved oxygen value even if various types of aerations are tested. The system comprises of DO sensor, water flowmeter, anemometer, PVC pipes, water pump, air compressor pump, and truck tyre tubes. The PVC pipes consisting of a main drainage hole, 5 holes for dissolve oxygen data collection, 1 hole as the location of aerator system, and connectors were designed as the major part of the system by using Computer Aided Design software. The main drainage hole (horizontal pipe) was designed to be 288.5 cm in length, while the measured holes (vertical pipes) were designed to be 45.7 cm in height. By considering a systematic approach, the designed system is hopefully able to solve measuring issue of dissolved oxygen in moving water and to provide a better evaluation of water treatment process.

1. Introduction

Dissolved oxygen (DO) is a measure of the amount of oxygen dissolved in a body of water as indication of the water quality and its ability to support a balanced aquatic ecosystem [1]. DO is necessary for the survival of many aquatic organisms like fish, invertebrates, bacteria, and underwater plants. Other than for respiration, DO is also essential for the decomposition of organic matter [2]. Upstream activities (farming, sewage treatment, and power plants) cause excess nutrient runoff and stimulate algae blooms in a river. As algae die off, decomposition will occur which uses up dissolved oxygen in a river. Eventually, hypoxia (low oxygen) and anoxia (no oxygen) conditions may occur and reduce the ability of a river to support other aquatic life [3].

Water aeration is a process of increasing or maintaining the oxygen saturation of water to improve water quality, to lessen odour of water, to reduce nutrient load, to create a better aquatic habitat, to control mosquito breeding, and to diminish the muck [4]. Naturally, the oxygen is dissolved into the water through the atmosphere or as a plant byproduct (photosynthesis). As shown in equation (1), the DO produced will peak during daylight hours and decrease at night. Since aquatic photosynthesis is light-dependent, this process is insufficient to maintain optimum DO levels [5]. As demonstrated by Dong et al. [6], a man-made approach is introduced as an alternative aeration in remediating untreated rivers by mixing oxygen (from the air) and water quickly. Generally, there are 2 practises of aeration, which are surface and subsurface aeration as summarized in table 1. The former is by exposing
water in the form of droplets or thin sheets of air. While, the latter is by exposing water in the form of small bubbles that is allowed to rise through water.

\[
6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{Aquatic photosynthesis}} 6(\text{CH}_2\text{O}) + 6\text{O}_2
\]

(1)

**Table 1.** Comparison of man-made aeration methods [7–8].

| Methods | Surface aeration | Subsurface aeration |
|---------|------------------|---------------------|
| Approaches | Placing the oxygen into the water through the surface. | Injecting the oxygenated water into the lake or river through the bottom. |
| Examples | • Fountains • Paddlewheels • Water jet | • Jet aeration (venturi principle) • Air compressor pump (fine/coarse bubbles) |
| Advantages | • Portable • Suitable for the most extreme environments, e.g., paper plants, chemical industry • Good in shallow water | • Low power consumption • Good in deep water • Appear hidden to any observers • Little power consumption |
| Disadvantages | • High power consumption • High maintenance • Ineffective in deep water | • More complicated to set up • Not suitable for rough environments |

According to Cooke et al. [4], in stagnant water, such as in pond, lake, and reservoir management, aeration techniques are widely used to avoid low oxygen levels or algal blooms. Measuring DO in moving water such as in a river is more challenging compared to a stagnant water. Although moving water such as in a river tends to contain a lot of DO, the level of DO is easy to fluctuate. Hence, this paper attempts to present a novel development of aeration measurement system that able to evaluate water treatment process in a river. This paper will first discuss on the review of existing dissolved oxygen measurement methods before discussing a full development of novel aeration measurement system.

2. Review of existing dissolved oxygen measurement methods

The existing methods to measure dissolved oxygen in water has been reviewed and summarized in table 2. There are 3 methods available for measuring DO concentrations, which are titrimetric method, colorimetric method, and sensor method. The first method (also known as the Winkler method) was developed in 1888 and has been recognized as the standard for analysing DO concentration [9]. While it is a low cost option, this method can be time-consuming, subjected to sample contaminants and interferences, which may lead to human error and inaccuracies [10]. Colorimetric method was designed then for quick and simple measurement. As shown by Cao et al. [11], this approach also results in a low accuracy and produces chemical waste that has to be disposed of later. Alternatively, modern techniques involve either an electrochemical or optical sensor. The DO measurement is deployed in a water by attaching the DO sensor to a data logger, which can be sensed quickly. Several parameters can be recorded by the data logger such as DO concentration, temperature, salinity, barometer pressure, conductivity, and pH of water. Apart from its high cost, this method provide a flexible range and high accuracy of DO measurement [12].
Table 2. Comparison of dissolved oxygen measurement methods [13].

| Methods                        | Titration                                                                 | Colorimetry                                                                 | DO meter + sensor                                                                 |
|-------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| **Approaches**                | A titrimetric procedure based on the oxidizing property of dissolved oxygen.| Approximation of dissolved oxygen concentrations in a sample with the aid of colorimetric reagents. | The dissolved oxygen sensor is attached to a data logger (meter) for spot sampling. |
| **Examples**                  | • Winkler method                                                          | • Indigo Carmine                                                            | • Electrochemical sensor                                                        |
|                               | • Modified Winkler method                                                 | • Rhodazine D                                                              | • Optical sensor                                                                |
| **Advantages**                | • Low cost                                                                | • Low cost                                                                  | • Simple measurement                                                            |
|                               | • Quick measurement                                                      | • Quick measurement                                                        | • Quick measurement                                                            |
|                               | • Simple measurement                                                     | • Flexible range                                                           | • Flexible range                                                               |
|                               | • High accuracy                                                           | • High accuracy                                                            | • High accuracy                                                                |
| **Disadvantages**             | • Low accuracy                                                            | • Destructive method                                                       |                                                                                  |
|                               | • Sample contaminants                                                    | • Destructive method                                                       |                                                                                  |
|                               | • Time-consuming                                                         | • Destructive method                                                       |                                                                                  |
|                               | • Destructive method                                                      | • Destructive method                                                       |                                                                                  |

3. Development of novel aeration measurement system

A novel approach in measuring DO in moving water, specifically in a river was developed to evaluate the water treatment process so that the value of DO is more comparable even if different types of aerator are tested. Based on figure 1, the system consists of DO sensor, water flowmeter, anemometer, PVC pipes, water pump, air compressor pump, and truck tyre tubes.

![Figure 1. Illustration of aeration measurement system.](image-url)
The system was designed by using Computer Aided Design (CAD) software as shown in figure 2. The PVC pipes consist of a main drainage hole, 5 holes for DO data collection, 1 hole as location of aerator system, and connectors (to fix the measured DO holes and the main drainage). Water from a river is allowed to enter the main drainage hole so that the mass flow rate of water (in m³/s) able to be measured as summarized in equation (2).

\[
\text{Mass flow rate of water}, \quad V_{\text{water}} (m^3/s) = A_{\text{pipe}} \times V_{\text{water}}
\]

Where,

- \(A_{\text{pipe}}\) = Surface area of pipe (m²)
- \(V_{\text{water}}\) = Water velocity (m/s)

Hole 1, 2, 3, 4, and 5 are the first, second, third, fourth, and fifth holes, respectively designed to measure the DO of water in the main drainage hole. The diameter and length of main drainage hole are 15.2 cm and 288.5 cm, respectively. While the DO holes and the aerator hole were designed to have a diameter of 7.6 cm. In order to place the DO sensor properly, the measured DO holes were designed with height of 45.7 cm. By doing so, the data collection can be performed systematically.

Figure 2(a). Design of aeration measurement system; (a) Full design.
4. Conclusion
A novel aeration measurement system has been developed and discussed successfully to evaluate the water treatment process in a moving water, specifically in a river. Challenges in measuring DO in a moving water can be solved by establishing a systematic approach, which is by designing a main drainage hole, 1 aerator hole, and 5 fixed measured DO holes. Future works will focus on experimental validations to verify the efficiency of this measurement system. It is expected that the novel design of aerator measurement system will provide a better evaluation to support the improvement of DO in a river based on various aeration systems.
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