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Improving of Water Quality Parameters Using Stepped Cascade Aerator

Mohammed A. Al-janabi [1], Jabbar H. Al-Baidhani [2*]

Authors affiliations:
1) Department of Civil Engineering, College of Engineering, Al-Nahrain University, Baghdad, Iraq.
hmodhmody97@gmail.com

2*) Department of Civil Engineering, College of Engineering, Al-Nahrain University, Baghdad, Iraq.
jabbar.h.al-baidhhani@nahrainuniv.edu.iq

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Abstract

Hydraulic structures, including cascade aerators, may be acknowledged as important components in improving aeration efficiency because of the intense turbulent mixing combined with large air bubble entrapment at these structures. The main objective of the present study is to achieve maximum aeration efficiency and enhance the concentration of dissolved oxygen in the water since this is an important factor in improving water quality. The present study aims to determine the most proper geometric and dynamic parameters of a typical square-shaped stepped cascade with a total height of 120 cm, and sex steps. A tread of each step is 10 cm and a rise of each step is 20 cm, where aeration efficiency is maximized. The results of the study revealed that the maximum value of water aeration efficiency, meaning an increase in dissolved oxygen in the water using a stepped cascade aerator happened when flow rates of 15 L/min, 25 L/min, and 35 L/min with aeration efficiencies of 22%, 37%, and 42% respectively. Finally, the optimization of flow rates in aeration systems can lead to improved water quality parameters. The most important feature of the present study is the innovation of a natural method of water treatment that relies on the principle of mixing, coagulation, and flocculation by hydraulic methods, which works to reduce the costs of operation.

Keywords: Water Treatment, Flow Rate Efficiency Cascade Aerator, Dissolved Oxygen.

تحسين معايير جودة المياه باستخدام جهاز التهوية المتدرج

محمد علي عطية، جبار حمود عبد النبي

الخلاصة:

يمكن الاعتراف بالهياكل الهيدروليكية، بما في ذلك جهاز التهوية المتدرج، كمكونات مهمة في تحسين كفاءة التهوية بسبب الخلط المضطرب الشديد المقترن بانحباس فقاعة الهواء الكبيرة في هذه الهياكل. الهدف الرئيسي من هذه الدراسة هو تحقيق أقصى قدر من كفاءة التهوية وتعزيز تركيز الأكسجين المذاب في الماء، حيث أن هذا عامل مهم في تحسين نوعية المياه. تهدف الدراسة الحالية إلى تحديد المعايير الهندسية والديناميكية الأكثر ملائمة لجهاز تهوية بشكل شلال متدرج نموذجي مربع الشكل بارتفاع إجمالي ١٢٠ سم و٦ درجات. يبلغ طول كل درجة ١٠ سم وارتفاع كل درجة ٢٠ سم، حيث يتم تحقيق أقصى قدر من كفاءة التهوية. أظهرت نتائج الدراسة أن القيمة القصوى لكفاءة تهوية المياه، أي أن زيادة الأكسجين المذاب في الماء باستخدام جهاز التهوية المتدرج قد حدثت عند معدلات تدفق ١٥ لتر/دقيقة، ٢٥ لتر/دقيقة، و٣٥ لتر/دقيقة. مع كفاءة تهوية ٢٢٪، ٣٧٪، و٤٢٪ على التوالي. وأخيرًا، يمكن أن يؤدي تحسين معدلات التدفق في أنظمة التهوية إلى تحسين معايير جودة المياه. وأهم ما يميز الدراسة الحالية هو ابتكار طريقة طبيعية لمعالجة المياه تعتمد على مبدأ الخلط والتخثر والتلبد بالطرق الهيدروليكية مما يعمل على تقليل تكاليف التشغيل..

1. Introduction

Transferring oxygen from the gaseous phase to the liquid phase is facilitated by the process of aeration, which is essential for the treatment of water and wastewater. There are three types of aeration that are often used: diffused air aeration, mechanical aeration, and gravity aeration. Gravity aeration is the most cost-effective method of raising dissolved oxygen (DO) levels if the site's constraints and hydraulic considerations allow it [1]. A simple weir, an incline

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corrugated sheet, or a graded cascade may all be used to provide gravity aeration. For a long time, stepped cascades have been used to dissipate energy, aerate, or remove volatile organic compounds (VOCs), especially in the context of dam spillways. The main feature of the stepped cascade is a series of steps that allow a thin layer of water to flow over them. As the water falls, bubbles form due to the suction of air. Between the air in these bubbles and the water, gas exchange takes place. As oxygen from the air permeates into the water, the DO concentration of the water rises. One possible way to reduce the dissolved nitrogen content is to use stepped cascades. Cascade aeration is used to cleanse drinking water by reoxygenating it and eliminating volatile organic compounds (VOCs) like chlorine and methane [2]. One of the most basic methods for enhancing the chemical and physical properties of water is aeration. The following are how the aeration or how aeration achieves the desired goals: The oxidation of some metals and gasses, as well as the turbulence produced when water and air interact, generate a scrubbing or wiping motion [3]. For many years, cascade has been used in hydraulic construction. It is the least expensive aeration technique for adding dissolved oxygen again and doesn't need any further maintenance [4]. One of the key elements affecting wastewater quality is dissolved oxygen (DO), which aerobic bacteria need to decompose organic compounds in wastewater. Depending on the selected treatment methods, the recommended aeration system may change. For example, large wastewater treatment facilities may employ complex mechanical systems to transfer oxygen to biological reactors, or they may opt for a more straightforward approach that involves using cascades to increase the concentration of oxygen in wastewater when needed [5]. Because biological life depends on oxygen in water, wastewater discharge into rivers has an effect that is mostly dictated by the oxygen balance of the system. Unfortunately, oxygen dissolves in water only a little. The quantity of oxygen that dissolves in water without causing a chemical reaction is referred to as soluble oxygen. It should be in the range of 5 and 9 mg/l. Aquatic life is harmed when concentrations are less than 1 mg/l[6]. Steep cascade aerators were initially intended for distinct hydraulic systems, and the oxygen movement inside them is now simulated using several equations. Mostly empirical, these equations are situation-specific [7]–[12]. An essential part of the oxygen transfer system is the hydraulics behind the tiered cascade aerators [13]. On a low-gradient stepped cascade, fundamental air-water flow parameters have been investigated in conjunction with dissolved oxygen measurements. The results of the experiment showed that the aeration effectiveness of a stepped chute depends on several factors, including depth, velocity, step geometry (height, length), and the starting degree of air entrainment. Additionally, it is characterized by a high degree of air entrainment, which increases the interface area accessible for mass transfer, and a high degree of turbulence, which preserves the maximum concentration gradient at the surface and facilitates solute dispersion [2]. For both the design discharge and the safety check, the flow must be identified as either nappe flow or skimming flow [14], [15]. Stepped cascades that replicated both nappe and skimming flow were used in the investigator's tests. The results imply that an effective technique for water aeration would be a moderately sloped stepped cascade running at nappe flow [13].

The primary objective of the majority of the literature on stepped cascade aerators that is now accessible is to adopt a unique design that results in high aeration efficiency and to characterize the hydraulic components based on the step geometry and hydraulic loading rate. However, researchers have not yet investigated the best step cascade unit design for use as pre- or post-aeration in the treatment of wastewater or drinking water. The goal of the present study is to identify the ideal geometric and dynamic parameters that could improve aeration efficiency in a standard square-shaped stepped cascade with a total height of 120 cm. The original achievement of the present study is to overcome the difficulties of mechanical mixing required in coagulation and flocculation and the accompanying increase in operating and energy costs.

2. Martials and methods

2.1. Design of Stepped Cascade Aerator

To design a cascade aerator, it needs to calculate the area required for the design, the several steps, the height of the aerator, the rise of each step, and the velocity of the inlet pipe [16]. The cascade aerator was designed in a square shape, based on the main factor, which is the maximum flow rate. As a result, a pump with a flow rate of 40 L/min and a flowmeter of 36 L/min to control the required flow, was used in the pilot plant. After that, it was concluded the appropriate design for the cascade aerator with several steps 6 a tread of each step is 10 cm and a rise of each step is 20 cm, the total height of the cascade aerator is 120 cm and the inlet pipe is of 2.5 cm. All dimensions are shown in figure 1 and figure 2. After designing the cascade aerator, it was implemented in the laboratory using transparent plastic sheets with the same dimensions as shown in Figure 3.

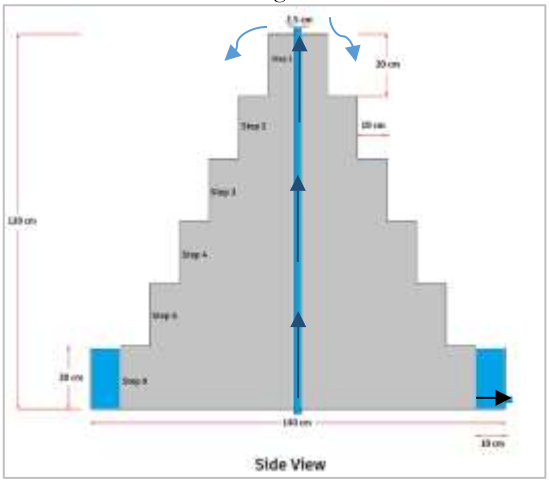

Figure (1): Side View of Stepped Cascade Aerator Used (All Dimensions are in cm)

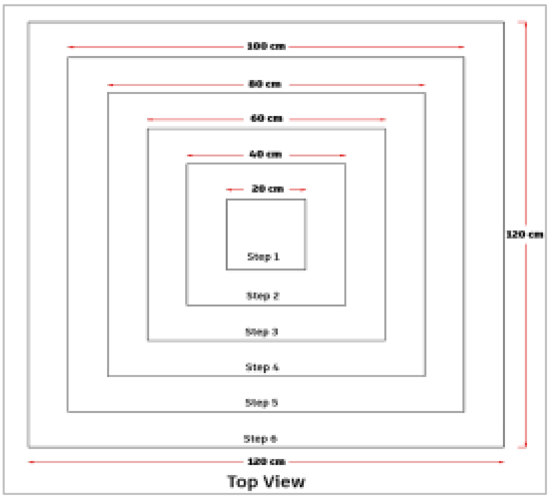

Figure (2): Top View of Stepped Cascade Aerator Used (All Dimensions are in cm).

Figure (3): Photos of Stepped Cascade Aerator Used

2.2. Oxygen Transfer Process

The difference between the present concentration C and the equilibrium or saturation concentration Cs of oxygen in the liquid determines the mass transfer rate, or dm/dt, of oxygen from the atmosphere to the turbulent liquid's body. According to [2] it is possible to be stated as:

$$\frac{dm}{dt} = \frac{dc}{dt} = KL\,\frac{A}{V}\,(Cs - C) \quad \ldots\ldots (1)$$

Where V is the volume across which transfer happens, A is the surface area associated with the volume, Cs is the saturation concentration, and t is the duration. KL is the coefficient of diffusion of oxygen in the liquid. The particular surface area, or surface area per unit volume, is another name for the word A/V.

The total oxygen transfer for a hydraulic structure may be determined using the deficit ratio r, which is defined as in line with [2]:

$$r = [(Cs - Cu) / (Cs - Cd)] \quad \ldots\ldots(2)$$

Where Cd is the dissolved oxygen concentration at the channel's downstream end and Cu is the dissolved oxygen concentration upstream.

According to (Gulliver et al, 1990), the oxygen transfer efficiency, or aeration efficiency, E, may be described as follows:

$$E = \frac{Cd - Cu}{Cs - Cu} = 1 - \frac{1}{r} \quad \ldots\ldots (3)$$

The ratio of oxygen shortage is r. The McGhee chart (1991) was used to calculate the saturation concentrations of Cs.

2.3. Dissolved oxygen and aeration efficiency (E_{20}%)

Water's solubility of oxygen is temperature-dependent. The amount of dissolved oxygen decreases with increasing temperature. Air bubbles are released from water during the heating process, which is a prominent example of this phenomenon. The water does not reach boiling point. Since rising water temperatures cause oxygen solubility to decrease, the dissolved oxygen and aeration efficiency in water were measured at an ideal temperature of 20°C, which is known as E_{20} [17].

The coefficient for temperature correction was created by (Gulliver et al, 1990).

$$E_{20} = 1 - (1 - E)^{\frac{1}{f}} \quad \ldots\ldots (4)$$

Where:
E: is the aeration efficiency at the water temperature of measurement (T) in℃.
E_{20}: The aeration efficiency at temperature 20℃.
f: correction factor and is described by [2]:

$$f = 1.0 + 0.021(T - 20) + 8.2 * 10^{-5}\,(T - 20)^2 \quad \ldots\ldots (5)$$

3. Experimental Work

The pilot plant established in the present study consists of: (1) an inlet tank with a capacity of 500 liters, (2) a flow meter of 36 L\min, (3) a pump of 40 L\min, (4) a stepped cascade aerator, (5) pipes of diameter 3\4", and (6) an outlet tank with a capacity of 40 liters. The experiment began by filling the tank with raw water, which was then transferred via the pump into the cascade aerator. The pump is connected to the flow meter by pipes to regulate the required flow rates. In the present study it was examined three different flow rates, which are 15 L/min, 25 L/min, and 35 L/min, that passed on a stepped cascade aerator, which contains six steps. Every flow rate passes on six steps, during which the dissolved oxygen levels are determined using a DO meter device. The obtained measurements are then compared to the dissolved oxygen levels present in the raw water. The major objective of the present study is to achieve maximum aeration efficiency and enhance the concentration of dissolved oxygen in the water since this is an important factor in improving water quality. The most important difference between the present study from previous studies is the adoption of a new shape of aerator that is connected to a hydraulic flocculator to complete the natural treatment process.

4. Results and Discussion

The results shown in Figure 4 are for the three flow rates of 15 L/min, 25 L/min, and 35 L/min that passed through the cascade aerator steps indicating that, as the flow rate increases, the aeration efficiency also increases. This is evident, as the aeration efficiency at Step 1 is 11% with a flow rate of 15 L/min, while at Step 6, it has increased to 22%. In the second flow of 25 L/min, the aeration efficiency increases to 26% and that shows a continuing trend of improvement with higher flow rates. This trend is further solidified at Step 3, where the efficiency percentage rises to 29%, and continues to increase at Steps 5 and 6, reaching 34% and 37%, respectively. With the third flow of 35 L/min, the aeration efficiency also improves significantly. The maximum aeration efficiency of 42% was achieved in step 6. This emphasizes of finding the best flow rate of aeration systems that should be chosen.

Increasing the flow rate causes the cascade aerator to move faster, which increases the shear between the liquid and gas phases. This increase in energy dissipation may result in smaller bubbles emerging. As a result, the mass transmission contact area is growing [18]. Increased velocity of the water in the cascade will be indicated by a larger water flow rate, which will cause further bulk liquid acceleration and turbulence with each step [19], [20] . The main finding of the present study is when increasing the flow rates of water and passing on a stepped cascade aerator, dissolved oxygen increases significantly, and the conclusion is in good agreement with previous studies. One of the most important factors that are highly sensitive to the nature aeration process is the amount of flow rate passing through the step of the stepped cascade aerator

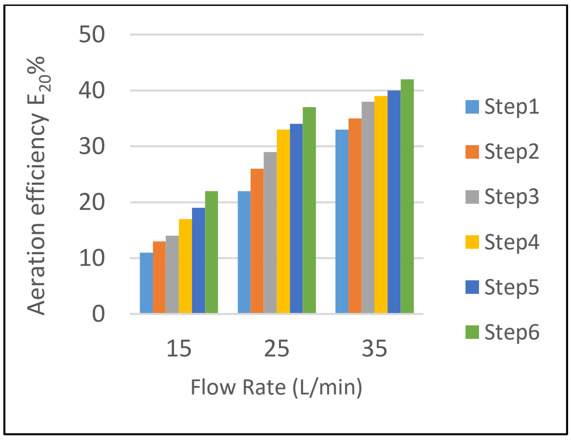

Figure (4): Relationship for All Cascade Aerator Steps Between Flow Rates and Aeration Efficiency

5. Conclusions

The strengths of the present study are the possibility of achieving hydraulic mixing between alum and water in addition to the possibility of increasing the concentration of dissolved oxygen in the water using a hydraulic aerator. The performance of aeration of a cascade aerator is highly dependent on the flow rate and geometry of steps. This emphasizes the need for careful optimization of flow rates in aeration systems to achieve maximum aeration efficiency. The results of the present study indicated that obtaining the maximum value of water aeration efficiency using of stepped cascade aerator are 22%, 37%, and 42% for flow rates of 15 L/min, 25 L/min, and 35 L/min. In general, optimizing flow rates in aeration systems can lead to improved efficiency and performance.

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