 

# An Investigation of Effect of Low-Gradient Stepped Cascade with Different End Sill Shapes on Aeration Performance of Marginal Water

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**Abstract**
The primary purpose of water aeration is to increase the oxygen saturation of the water. This can be achieved by using hydraulic structures because of substantial air bubble entrainment at these structures. In a stepped cascade, the provision of steps can produce significant energy dissipation. Efforts to increase the DO level of rivers require significant expenditures each year . Organic waste from municipal, agricultural, and industrial sources may overload the natural system causing a serious depletion of the oxygen supply in the water . In this study the aeration efficiency of Low-Gradient stepped cascade for polluted water is studied and the effect of COD on aeration efficiency is presented.
**Keywords:** stepped cascade weir, aeration , COD ,Dissolved Oxygen, Marginal water

## 1. Introduction

Aeration enhancement by macro-roughness is well-known in water treatment, and one form of it is the aeration cascade. In-stream cascades have been built along polluted and eutrophic streams. For example, in Chicago five re-aeration cascades have been built recently to re-oxygenate the depleted water of the Calumet waterway. In large dams, another issue is the downstream nitrogen super saturation. Similarly, stepped weirs are designed downstream of large dams to control nitrogen super saturation. For example, despite the associated hydropower loss, a two-steps re-aeration cascade was added downstream of the Petit-Saut Dam in French Guyana to treat turbined waters which had unacceptably high methane content. Re-aeration cascades are used in water treatment for re-oxygenation, de-nitrification or VOC removals. In the treatment of drinking water, cascade aeration may be used to remove chlorine and to eliminate or reduce offensive taste and odour. Toombes, L., and Chanson, H., (2000) and Chanson and Toombes (2000) considered aeration in small-slope stepped cascades. Luke Toombes (2002) conducted a systematic, detailed investigation of the physical flow characteristics of a low-gradient stepped cascade and provides an analysis of the flow patterns down a flat-stepped chute, including flow depths, velocities, nappe trajectories, and characteristics of the three-dimensional patterns of the flow. Chanson, H. and Toombes, L. (2002b) conducted experiments in a large, flat stepped chute θ=3.4° based upon a Froude similitude. Baylar & Emiroglu (2003) studied the aeration efficiency of flat stepped-channel chutes (14.481 ≤ α ≤ 22.551) and Emiroglu & Baylar (2003) conducted the aeration efficiency of stepped-channel chutes with and without end sill in a large laboratory stepped chute. L. Toombes and H. Chanson (2005) focused on analysis of basic air–water flow properties on a low gradient stepped chute, combined with dissolved oxygen measurements.

This paper describes an experimental investigation into aeration efficiency of low gradient stepped cascade , and in particular, the effect of COD on the aeration efficiency.

## 2. Oxygen Transfer Process

The importance of hydraulic structures such as weirs and falls for water quality improvement in rivers is well-known. Weirs have been used to increase dissolved oxygen (DO) concentrations in rivers. The Task Committee on Gas Transfer at Hydraulic Structures of the Technical Committee on Hydraulic Structures of the ASCE (1991) identified some basic physical and hydrodynamic processes that affect gas transfer at hydraulic structures and concluded that the impact of these processes is governed mainly by fluid mechanics and flow conditions. The identified processes are: (1) turbulent mixing at the water surface and within the body of the flowing water; (2) increased mass transfer due to increased interfacial area resulting from entrained air bubbles; and (3) mass transfer enhancement resulting from the hydrostatic pressure of tailwater. Oxygen transfer at hydraulic controls such as weirs can be measured by (Gameson 1957):

$$r = = \frac{Cs - Cu}{Cs - CD} \quad (1)$$

where $r$ = deficit ratio; $CS$ , $CU$, and $CD$ = saturation, upstream, and downstream oxygen concentrations (mg/L), respectively. The saturation concentration in distilled, deionized water may be obtained from charts or equations. This is an approximation because the saturation DO concentration for natural waters is often different from that of distilled, deionized water due to the salinity effects. In this study, the saturation concentrations were determined by the chart of McGhee (1991).The deficit ratio varies from one for no oxygen transfer to infinity for complete oxygen transfer. The deficit ratio is related to the oxygen transfer efficiency *E* as

$$E = 1 - \frac{1}{r} = \frac{CD-Cu}{Cs-Cu} \qquad (2)$$

Eq. (2) expresses the change in concentration as a fraction of the initial deficit. If no transfer occurs, *E* = zero; if a complete transfer occurs, *E* = 1. The quantities *r* and *E* are measures for comparing oxygen transfer from one structure to other structures. Gulliver and Rindels (1993) suggested the following equation for relating oxygen transfer at $20^0$C to transfer at other temperatures, reporting a maximum error of 0.03% between 0 and $40^0$C

$$1 - E_{20} = (1 - E)^{1/f} \qquad (3)$$

where $E_{20}$ = oxygen transfer efficiency at $20^0$C; $f = 1.0 + 0.02103(T - 20) + 8.261 * 10^{-5}(T - 20)^2$; and T = water temperature ($^0$C). Eq. (3) can be expressed in terms of the deficit ratio as

$$r_{20} = r^{1/f} \qquad (4)$$

where $r_{20}$ = deficit ratio at $20^0$C.

## 3. Experimental Arrangement and Experiments

The pilot model has been designed and constructed in an existing underground concrete channel in hydraulic laboratory in college of engineering-AL-Mustansiria University. The channel of 32 m length , 1.2 m width and 1.0 m depth below ground level . The stepped cascade weir structure of length 10 m and of height 0.8 m consist of 5 bays each bay of 2.0 m length , 1.2 m width , 0.2 m height and the end sill of 0.1 m height . The cascade structure is designed and constructed from steel angle of dimension 50*50 *4 mm bolted to each other to form a frame and the frame is covered with pieces of granite tiles of dimension (2m*0.60m*0.02 m) connected to each other by concrete mortar and silicone for water proof . A concrete weir is constructed at the upstream of the cascade structure to evaluate the discharge of the water .A pump of 100 l/sec capacity located at the downstream of the structure was used to recycle the water to an existing elevated flume of dimension (0.8m*0.9m * 20 m ) as shown in plate (1) .The cascade steps is shown in figure (1).

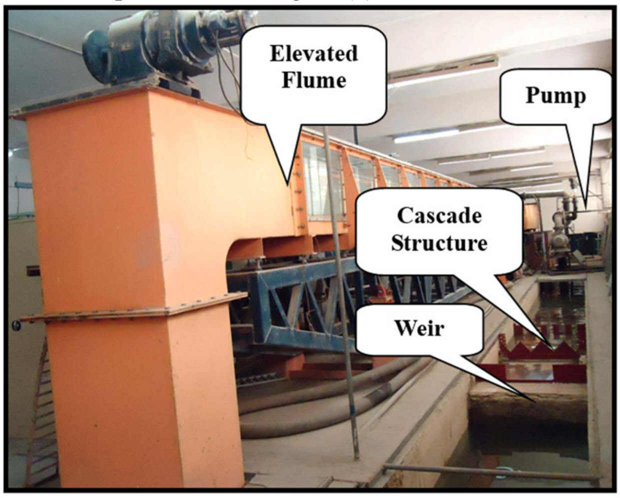


**Plate (1)**: General arrangement of Pilot Project

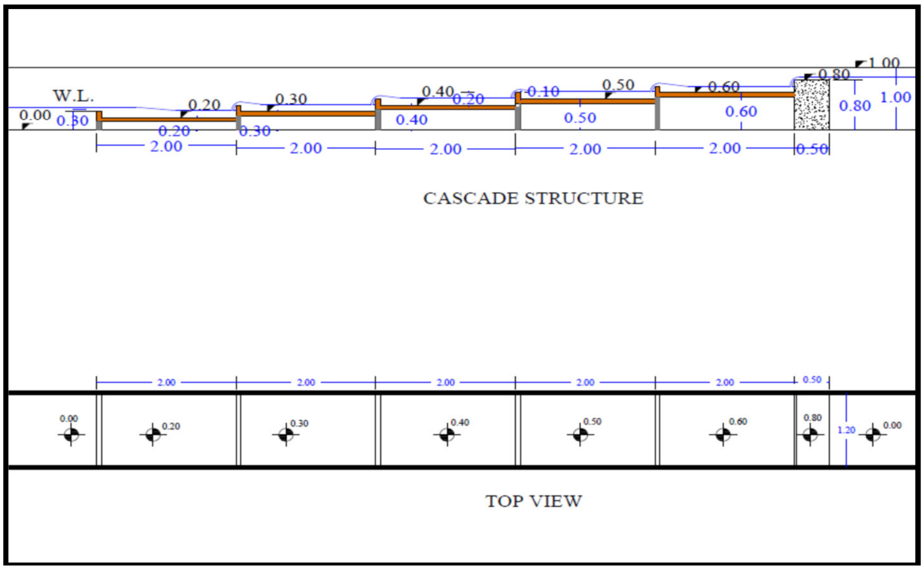


**Figure (1):** Cascade steps for pilot project

Two flow meters were used to calculate the discharge and the weir was calibrated to measure the discharge from the depth of water over the weir. The pump is connected to a suction pipe of diameter 0.3 m a delivery pipe of diameter 0.25 m and a check valve of the same diameter was installed to control the discharge .During the experiments, a digital thermometer was used to measure water temperature. Since the saturation concentration of oxygen is a strong function of temperature, the aeration efficiency is also temperature dependent. To provide a uniform basis for comparison of different systems ,the aeration efficiency is often normalized to a 20°C standard. Gulliver et al. (1990) proposed the following equation to describe the The end sill is arranged as type (A), type (B), type (A), type (B), type (A) from the weir to the end of the structure as shown in plate (2)

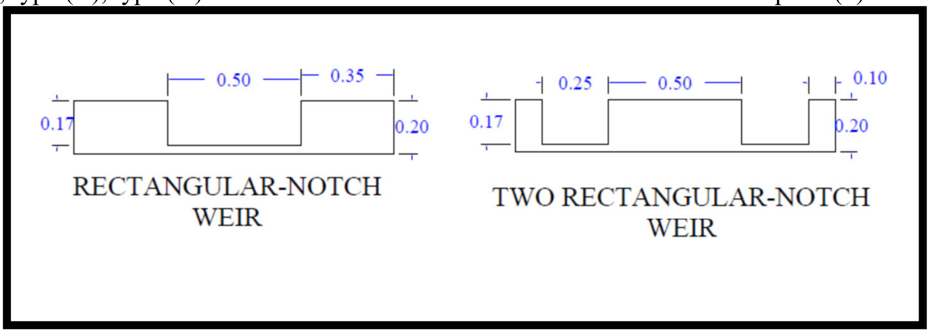


**Figure (2):** Type (A) Rectangular notch weir, Type (B) Two rectangular notch weir .

**Plate (2):** Arrangement of rectangular weirs

The discharge was measured by means of a flow meter installed in the supply line. The salt content of polluted water used for all of the experiments reported in this paper was low and was monitored constantly during the experiments to ensure there was no buildup of residues caused by the deoxygenating chemicals added to the water. Therefore, the results were not affected by the presence of any chemicals or pollutants.

DO measurements upstream and downstream of the stepped chute were taken using calibrated portable HANNA Model HI 9142 oxygen meters at the locations identified. Measurements were made by submersing the probe to a depth of approximately 0.20 m at sampling points. The DO meters were calibrated daily according to local atmospheric pressure, prior to use, by the air calibration method. Calibration procedures followed those recommended by the manufacturer. The calibration was performed in humid air under ambient conditions. From equation 2 it can be seen that the measurement of transfer efficiency becomes quite sensitive to measurement errors with a low upstream DO deficit. Gulliver and Wilhelms (1992) have stated that an upstream DO deficit of greater than 2.5 mg/l is normally required for accuracy in an oxygen-transfer efficiency measurement. Wormleaton and Soufiani (1998) found that the oxygen transfer efficiency, E, is sensibly independent of the upstream DO deficit.

## 4. Results and Analysis

In this study, the values of the aeration efficiency of stepped cascade were obtained for different COD ranged between (41-276) mg/l with discharge of 100 l/sec the result is shown in figure (3).

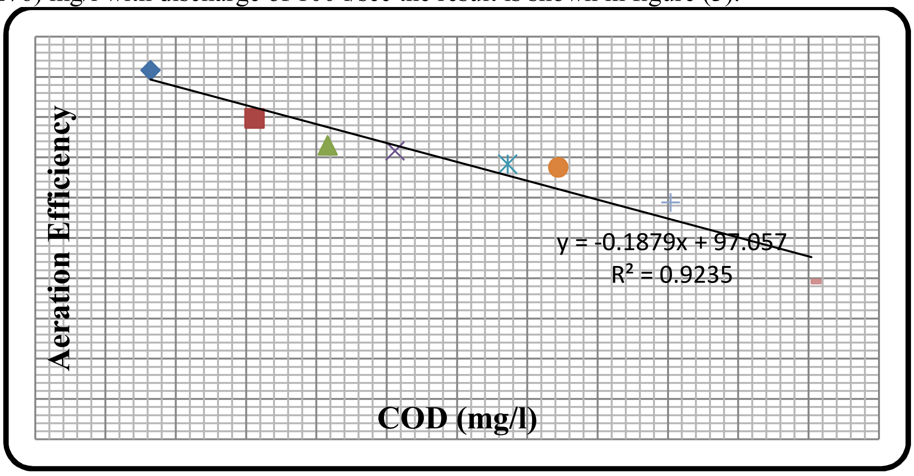


**Figure (3):** relation between Aeration Efficiency with COD

The relationship of aeration performance and time for different levels of marginal water can be formed as follows.

E(20)=32.765-0.076(COD)+[ 3.5343-0.0083{COD}]ln(t)

Figures (4,5,6) represent variation of DO with No. of cycle for COD (41,168,276) mg/l and discharge of 100 l/sec.

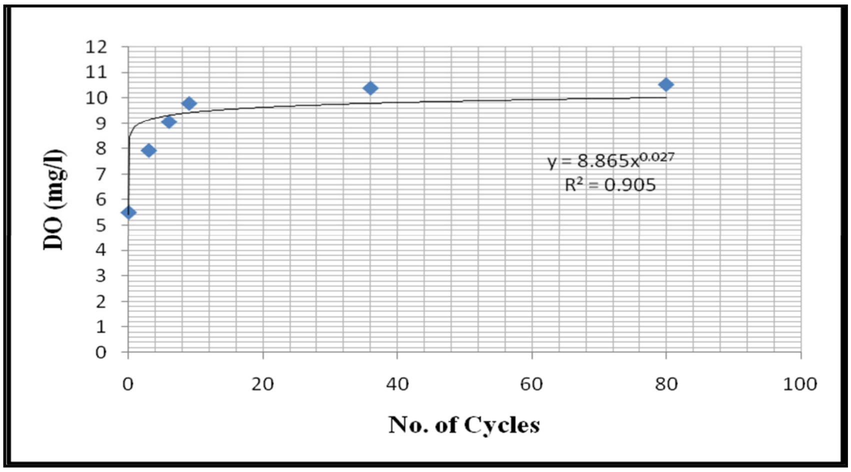


**Figure (4):** Relation between Efficiency with No. of cycles for COD=41 mg/l

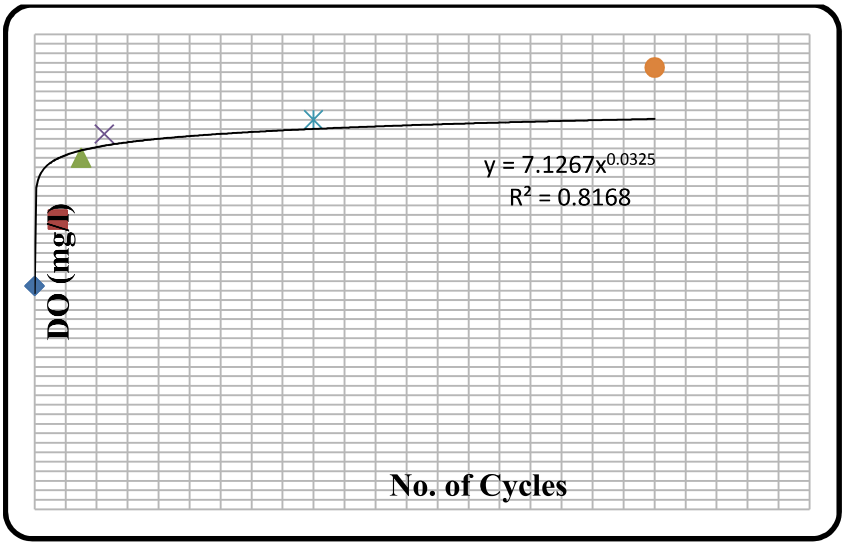


**Figure (5):** Relation between Efficiency with of cycles for COD=168 mg/l

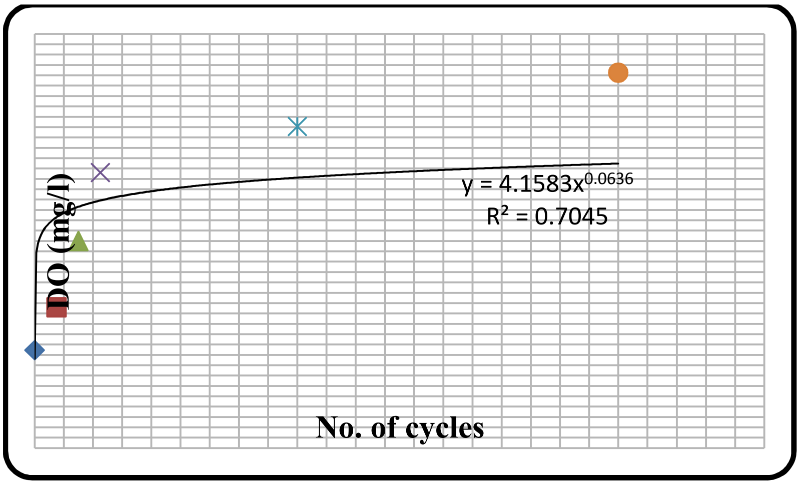


**Figure (6):** Relation between Efficiency with of cycles for COD=276 mg/l

## 5. Conclusions

Series of laboratory experiments were run on low-gradient stepped cascade in order to determine aeration performance. An empirical correlation was developed that predicted the oxygen transfer efficiency. Based on the findings of this study, the following conclusions can be drawn:

- The results showed that nappe flow was observed for all cases
- The results shows that DO is increasing with time and number of cycles.
- Scaling of aeration data to prototype size is virtually impossible, largely due to the relative invariance of bubble size. The experiments described in this paper cover discharge that are considerably large as aprototype applications. Additional testing is necessary to assess the effect of aeration efficiency for stepped cascade with end sill when the shape of end sill is of different shapes.
- The COD is an effective factor in aeration efficiency and as COD increases, the aeration efficiency is decreases.

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