ENHANCEMENT OF SELF-PURIFICATION OF STREAMS USING STEPPED AERATION

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ABSTRACT

Enhancing the self-purification of streams has become an important task of wastewater management. Gabal EL Asfar drain, located in Cairo, Egypt, transfers the excess raw wastewater from Berka WWTP at an approximate flow rate of 250,000 m^3/d to be discharged into Belbies drain without any treatment, thus affecting the surrounding environment, human health, and the aquatic life.

In this paper, samples of wastewater, taken from Gabal EL Asfar drain, has been utilized to investigate the effect of falling height and BOD_5 concentrations on the increase of DO in wastewater upon falling over stepped weirs. Utilizing tap water, as a reference, the first run of tests yielded that the concentration of DO increased from 0.0 mg/l at 0.0cm-falling height, after de-oxygenation using Na_2SO_3, to 2.95 mg/l at a falling height of 100 cm. The second run of tests utilized wastewater with a BOD_5 concentration of 150 mg/l. DO increased from 0.0 mg/l at 0.0 cm-falling height to 2.45 mg/l at 100 cm-falling height. A third run of tests with the same configurations was done to investigate the effect of BOD_5 concentration in the falling water on the DO level gained upon falling from different heights. The BOD_5 concentrations utilized in this run ranged from 60 mg/l to 180 mg/l and consequently different DO levels were obtained. The obtained results showed that self-purification of streams could be enhanced using cascade aeration.

Keywords: Cascade Aeration, Dissolved Oxygen, Self-purification, Streams

INTRODUCTION

Streams and rivers play an essential role in water supply, flood flow reduction, recreation and in enhancing the scenic quality of the environment. Moreover, they are considered the main source for water supply used in drinking, irrigation, industrial and municipal water supply and disposal, navigation, and fishing (UNESCO/WHO/UNEP, 1992). Many countries are encountering polluting problems in their water. For instance, the United kingdom is suffering from the pollution of its rivers and streams due to the disposal of chemical contaminants; Key Largo in Florida has a growing oil pollution problem affecting the marine ecosystem of the coral reefs; (Krantz and Kifferstein, 2005); Kansas city is suffering from the feacal coliform entering its streams and rivers due to the disposal of wastes into the water and the runoff from areas with high levels of domestic livestock, wildlife, or human wastes (Devlin et al., 2000). Moreover, India has crucial water quality issues in its rivers due to the presence of feacal contamination from human and animal wastes being disposed without adequate collection nor treatment; in addition, there is the Yamuna River which flows through towns and cities is negatively affected by the organic pollutants as well as the Damodar River where there are large concentrations of heavy metals arising mainly from electroplating, tanning and metal industries (Water quality issues, 2005). Streams and rivers receive lots of point source and non-point source pollution in addition to receiving residual waste daily produced by the community. Some of these pollutants could be inorganic silt derived from surrounding lands, organic particles of dead plants and animals sinking down the water column leading to oxygen depletion in the streams (Limnology, 2001, Velz, C. 1984). Hence, the concentration of DO decreases in the lakes causing the death of fish by suffocation and threatens the aquatic life specially when oxygen is being utilized through the biological and chemical processes by an amount that surpasses that oxygen generated from re-aeration and photosynthesis.

A technique that has been successfully used for enhancing the DO in streams is the weir aeration similar to that used in the urban waterfall for Chicago side stream elevated pool aeration (Mueller, J. *et al*, 2002). The mechanism of aerating over weirs includes three steps. The first one includes minor aeration from water flowing over the weir directly to the jet. The second includes aeration on the surface of the pool from the jet depending on the intensity of surface agitation. The third and most contributing to the oxygenation process is the bubble aeration from air entrained in the jet and pool to which the jet is discharging. The drop height of the weir also has a significant effect during aeration. As it increases, the characteristics of the jet change from smooth to rough jets, then to oscillating jets and finally to jet breakup (Wormleaton & Soufani, 1998). Aeration efficiency increases with jet height, with the rough and oscillating jets providing significant surface agitation and a large amount of closely packed bubbles entrained in the pool. Although a drop height causing jet breakup has the highest efficiency, the rate of increase with drop height is significantly lower than that of the rough and oscillating jets (Mueller, J. *et al*, 2002).

In Egypt, Bahr EL Baqar drain, for example, originates North of Cairo, is considered to be one of the most polluted streams in Egypt. It lies between the Damietta branch of the River Nile and the Suez Canal and runs for 106 km before discharging into Lake Manzala. It includes two upstream branches namely Qalubyia and Belbies drains with lengths of 73 and 66 km respectively. Bahr EL Baqar drain receives large volumes of municipal and industrial wastes as well as agriculture drainage water from the Eastern Delta and contributes almost 45% of the total discharge of Lake Manzala (El Baz, A. 2003). The main sources of pollution in Bahr EL Baqar drainage system include the discharges of agricultural waste including pesticides, illegal industrial waste, and discharge of illegal domestic untreated waste. Such pollutants lead to the depletion of oxygen over a long distance. EL Qalubyia Drain is considered to be one of the main suppliers of pollution of Bahr EL Baqar drain. The actual overall flow of wastewater has reached a value of 5.2 million cubic meter per day despite that the drain was designed to carry a flow of 3.92 million cubic meter per day (El Monayeri, D. *et al*, 2002). Samples were taken from different locations along the drain and results are presented Table 1:

Table 1: Characteristics of the wastewater flowing in El Qalubyia drain

Item	Minimum Value	Maximum Value
BOD_5, mg/l	42	516
COD, mg/l	91	1064
SS, mg/l	12	202
DO, mg/l	0.00	0.00
PH	6.89	7.84
Temperature, ^oC	34	39
Nitrate – N_2, mg/l	0.00	4.10

(El Monayeri, D. *et al*, 2002)

The above values show that the main critical parameter in the drain is the value of DO which has a concentration of 0.00 mg / l. This could be due to the increase in BOD_5, decrease in algae, increase in turbidity and water depth. **Figures 1 and 2** represent the situation in Qualubyia drain. Attempts to enhance these natural water systems all over Egypt have been of major concern lately as these systems have become a threat to all living organisms including human beings.

Figure 1: Tremendous quantities of solid wastes dumped near and into the drain

Figure 2: Enormous amount of weeds growing vigorously across the drain

As any system of stream sanitation and pollution control is dependent on natural self-purification (Velz, C. 1984), the problem understudy is to investigate the influence of cascade aeration on the self-purification of streams in terms of increasing the level of DO to upgrade the quality of streams and consequently enhance the aquatic life. The objective of the present work is to delineate the relation-ship between the falling water height over the stepped aeration and the gain of DO at different BOD concentrations.

Site Description and Experimental Program

The flow rate of wastewater in the drain is approximately 250,000 m^3/d flowing at a depth of 1.0 m and a cross-sectional area of 12 m^2 as presented in **Figure 3**. Targeting the investigation of the impact of cascade aeration geometry on increasing the concentration of dissolved oxygen in wastewater at different concentrations of BOD_5, an experimental program has been designed and executed in Gabal EL Asfar laboratory. In this program, samples taken from Gabal EL Asfar drain have been tested mainly to measure the levels of DO at different water falling heights. These falling heights varied from 0.0 cm to 100 cm with an interval of 10 cm. The influence of BOD_5 concentration in the falling water has been investigated as well. The BOD_5 concentrations utilized in this work varied from 60 mg/l to 180 mg/l.

Figure 3: Cross-Section of Gabal EL Asfar Drain

Sodium Sulphite was used to deplete any DO present in both tap water (utilized as a reference) and wastewater investigated samples. Samples have been allowed to fall from a 5.0 liter volume jar (used during the experiment with a tap) and collected in a beaker located at different heights from the jar tap as illustrated in **Figure 4**. A detention time of 140 sec (Metcalf & Eddy, 2003) was used to measure the level of DO at every step (height). The flowrate of water from the beaker was 0.75 m^3/d (0.0087 l/s). A constant volume of 200ml of the sample was filled to measure the concentration of DO. The beaker was place on a magnetic stirrer to assure accurate initial DO concentrations. The temperature of wastewater ranged from 20^{o}C to 23^{o}C. The level of DO was done every 10 cm from 0.0 to 100 cm for clean water, wastewater and wastewater with different BOD_5 concentrations.

Figure 4: Arrangement utilized in measuring DO conc. at different heights

RESULTS

In the following sub-sections, the results obtained from executing the designed experimental program in the present study shall be presented.

i. Effect of water falling height on the level of DO in tap water:

To investigate the effect of water falling heights on the level of DO in tap water samples, the dissolved oxygen concentrations were measured in samples collected at different falling heights ranging from 0.0 cm to 100 cm with an interval of 10 cm. The initial level of DO was 4.0 mg/l at a temperature of 20^{o}C. De-oxygenation was done using diluted sodium Sulphite (Na_2SO_3) till the level of DO reached 0.0 mg/l. (1.5 ml of 50 gm Na_2SO_3 diluted in 250 ml of water). The level of DO in the falling water samples collected at different falling heights increased from 0.0 mg/l at 0.0cm-falling height to 2.95 mg/l at a falling height of 100 cm. **Table 2** shows the results obtained from this run of the experimental program.

Table 2: Effect of water falling height on the level of DO in tap water

H (cm)	0.0	10	20	30	40	50	60	70	80	90	100
DO conc. (mg/l)	0.00	0.9	1.7	1.8	2.1	2.3	2.4	2.6	2.6	2.9	2.95

ii. Effect of height on the level of DO in wastewater with a BOD_5 concentration of 150 mg/l:

To investigate the effect of water falling heights on the concentration of DO in wastewater, the experimental procedure outlined above was repeated using samples of wastewater from Gabal EL Asfar drain. The utilized wastewater has a BOD_5

concentration of 150 mg/l. The initial level of DO in the investigated wastewater samples was 1.2 mg/l at a temperature of 20^oC. De-oxygenation was done using 8.0 ml of 50 gm Na_2SO_3 diluted in 250 ml of water till the level of DO reached 0.0 mg/l. The level of DO in the falling wastewater samples collected at different falling heights has been measured. The level of DO in the falling wastewater samples collected at different falling heights increased from 0.0 mg/l at 0.0cm-falling height to 2.45 mg/l at a falling height of 100 cm. **Table 3** shows the results obtained from this run of the experimental program.

Table 3: Effect of water falling height on the level of DO in wastewater

H (cm)	**0.0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
DO conc. (mg/l)	0.00	0.85	1.20	1.70	1.80	2.00	2.10	2.25	2.30	2.40	2.45

iii. Effect of water falling height on the level of DO in wastewater for different BOD_5 concentration:

To investigate the effect of both water falling height and BOD_5 concentration on the level of DO in wastewater, the experimental procedure outlined above was repeated using samples of wastewater from Gabal EL Asfar drain. The utilized wastewater has BOD_5 concentrations varying from 60 mg/l to 180 mg/l. The initial level of DO in the investigated wastewater samples was 1.2 mg/l at a temperature of 20^oC. De-oxygenation was done using different volumes of 50 gm of Na_2SO_3 diluted in 250 ml of water till the level of DO reached 0.0 mg/l. The level of DO in the falling wastewater samples collected at different falling heights have been measured for each investigated BOD_5 concentration. The level of DO in the falling wastewater samples, with different BOD_5 concentrations, collected at different falling heights increased from 0.02 mg/l at 0.0cm-falling height (for all investigated BOD_5 concentrations) to 2.44 mg/l at a falling height of 100 cm. **Table 4** shows the results obtained from this run of the experimental program as well as the volumes of Na_2SO_3 utilized for de-oxygenation purpose.

Table 4: Effect of various heights on the concentration of DO in wastewater for different BOD_5 concentration

Item	BOD_5 (mg/l)						
H (cm)	180	158	125	113	99	74	
0.00	0.02	0.02	0.02	0.02	0.02	0.02	DO Conc. (mg/l)
10	0.44	0.30	0.45	0.27	0.32	0.44	
20	0.83	0.96	0.75	0.53	0.61	1.14	
30	1.04	1.10	0.72	1.08	0.78	1.14	
40	1.35	1.28	1.05	1.18	1.05	1.50	
50	1.59	1.35	1.56	1.40	1.08	1.83	
60	1.62	1.73	1.49	1.33	1.43	1.57	
70	1.99	1.65	1.52	1.35	1.63	1.61	
80	2.09	1.73	1.76	1.59	1.87	1.90	
90	2.05	1.98	2.00	1.34	2.15	1.81	
100	2.25	2.44	2.12	1.8	1.96	2.02	
T_w °C	20.6	21.4	22.3	22	21.8	21.2	
Na_2SO_3 (ml)	20	4.5	7.0	9.0	0.0	0.0	

Discussion

The increase in the level of DO in water and wastewater upon falling over stepped weirs has been investigated in this paper via executing the experimental program outlined before. The obtained results showed an increase in the level of DO upon increasing the falling height. This increase differed from tap water to wastewater for the same falling heights. For all falling heights investigated in this paper, the increase in DO level of wastewater varied from 5 – 20 % less than the corresponding gain for tap water as illustrated in **Figure 5**.

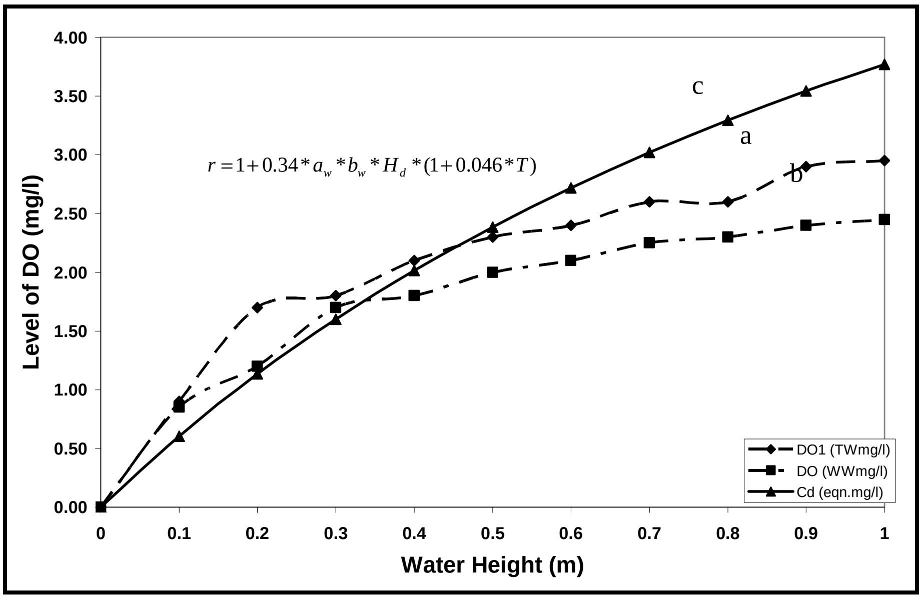

Figure 5: DO level vs. water falling height for:
(a) Tap water (TW), (b) Wastewater (WW), and c) Mathematical equation (C_d)

In the above figure, **curve a** shows an increase in the level of DO from 0.0 mg/l to 2.95 mg/l as the falling height increased from 0 to 1.0 m, respectively, at 10 cm interval for tap water samples. The increase in the level of DO varied from 0.0 mg/l to 2.45 mg/l as the falling height increased from 0 to 1.0 m, respectively, at 10 cm interval for wastewater samples as shown in **curve b**. On the other hand, **curve c** represents the theoretical expected downstream concentration of DO in a stream using one of the most common mathematical models (Mueller et al., 2002) from which the expected DO level downstream the cascade aeration can be computed using the following equation:

$$\frac{1}{r} = \frac{C_\infty^* - C_d}{C_\infty^* - C_u} \qquad (1)$$

where: C_∞^*: saturation water concentration (9 mg/l), C_d: downstream oxygen level, C_u: upstream oxygen level, and r = oxygen deficit ratio computed from the following relation:

$$r = 1 + 0.34 * a_w * b_w * H_d * (1 + 0.046 * T) \qquad (2)$$

where: a_w = 0.85 (factor representing the quality of wastewater), b_w = 1.3 (factor representing type of weir, assume step weir for case understudy), H_d = height of step, and T = temperature of water (^oC).

Moreover, the same figure shows that upon falling over different heights, the increase in DO level measured from the experimental program does not comply with the corresponding values calculated from the model mentioned above.

However, the results obtained from the experimental program in this paper are in consistence with the work done by Wormleaton & Soufani, 1998 from which they concluded that the drop height of the weir has a significant effect during aeration. As it increases, the characteristics of the jet change from smooth to rough jets, then to oscillating jets and finally to jet breakup. In addition, the obtained results are in agreement with the work done by Mueller, J. *et al*, 2002 from which they concluded that aeration efficiency increases with jet height, with the rough and oscillating jets providing significant surface agitation and a large amount of closely packed bubbles entrained.

Regarding the impact of BOD_5 concentration in the wastewater on the enhancement of its DO level upon falling from different heights, **Figure 6** displays different increases in the level of DO for different BOD_5 concentrations ranging from 60 mg/l to 180 mg/l upon falling from different heights varying from 0.0 cm to 100 cm with an interval of 10 cm. This shows that the presence of organic matter in wastewater affects the effectiveness of stepped weir in enhancing the level of DO in wastewater flowing over the weir. This could be attributed to the different kinetics of the present micro-organisms that utilize the dissolved oxygen.

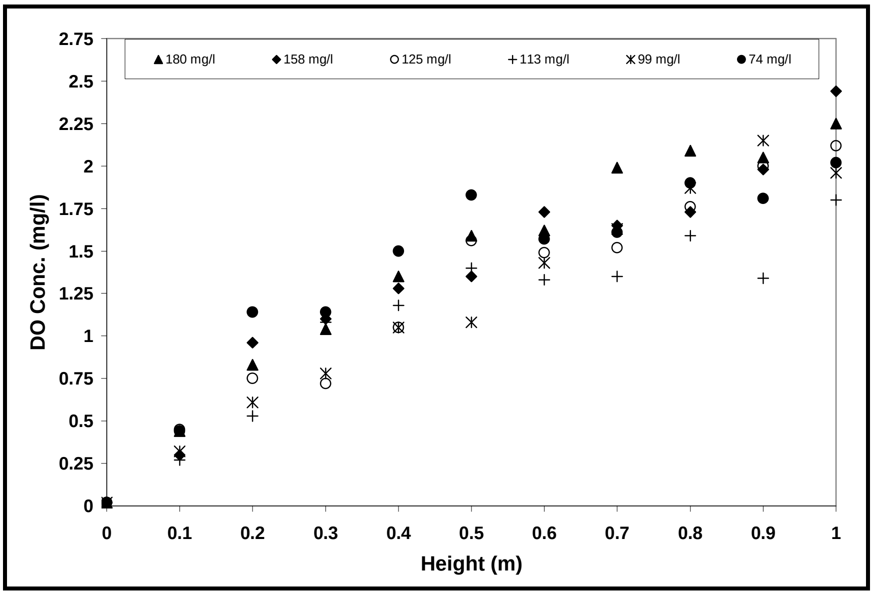

Figure 6: The effect of different heights and different BOD_5 values on the concentration of DO in wastewater

CONCLUSION

Based on the executed experimental program and limited to the obtained results, the following conclusions could be withdrawn:

1. For a certain BOD_5 concentration, the increase in DO level in wastewater appears to be less than that in clean water upon fall from the same water fall height. This difference varied from 5 – 20 % based on the falling height.
2. The presence of organic matter in wastewater could be one of the factors affecting the efficacy of stepped weir in enhancing the level of DO in wastewater flowing over the weir.
3. The increase in the level of DO in wastewater, with a BOD_5 concentration of 150 mg/l, doesn't exceed 2.5 mg/l upon falling from 1.0 meter height (compared with 2.95 gm/l for clean water).
4. A falling height of 0.7 m was required for wastewater sample with a BOD_5 concentration of 180 mg/l to reach a DO level of 2.0 mg/l. Researches showed that many types of fish and bottom dwelling animal can't survive in oxygen levels below 2-5 ppm (Krantz and Kifferstein, 2005).
5. To reach a DO level of 2.0 mg/l downstream the falling height, the wastewater fell from a height of 0.7 m.
6. The required falling heights to reach a DO level of 1.0 mg/l for different BOD differed from 18 cm to 28 cm to 38 cm for BOD_5 concentrations of 74 mg/l, 13 mg/l and 125 mg/l, respectively.

Based on the above lab tests, the results showed that self-purification of streams could be enhanced using natural cascade aeration. The results for increase of DO in clean water compared to that in wastewater show that the presence of organic waste in wastewater affects the amount of oxygen that could be dissolved during cascade aeration. Hence, the concentration of organic matter should be considered in the equations present in the literature for cascade aeration.

Thus further work and research concerning cascade aeration and self-purification of streams and rivers is recommended to be done.

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