WATER QUALITY IMPROVEMENT OF DRAINS POLLUTED BY WASTEWATER USING CONVENTIONAL WEIR

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ABSTRACT

In many arid and semi-arid countries water is becoming an increasingly scarce resource and planners are forced to consider any sources of water which might be used economically and effectively to promote further development. At the same time, with population expanding at a high rate, the need for increased food production is apparent. The potential for irrigation to raise both agricultural productivity and the living standards of the rural poor has long been recognized. In Egypt, agriculture is allocated, by far, the largest portion of available fresh water resources but increasing urbanization is creating an ever-increasing demand for water. However, most of the domestic waste water used by the growing urban population is not treated and is discharged directly into agricultural drains. The main aim of this study was to investigate the feasibility of using aeration weir systems in agricultural drains receiving domestic sewage to increase its quality by increasing the dissolved oxygen content (DO). This aims at enhancing the overall drainage water quality for reuse for irrigation by lowering the health risks. It also aims at achieving significant improvement in drainage water quality with both minimal land and mechanical energy use and obviously without impairing the main function of the drain. It will also assess the improved aeration performance. To achieve this aim a through literature survey was to asses the sate of art with regards aeration techniques used for improving the quality of drainage water. A physical model was built in order to experimentally verify the results and to examine the effect of the different variables on the aeration efficiency of water using drop structures; conventional weirs. All other factors controlling the dissolved oxygen concentration and governing aeration over weirs were discussed and the optimum solution was proposed. It was found that drop structures can be efficiently used for the indirect aeration of water with high efficiencies.

1- INTRODUCTION

Water with high quality is becoming more and more a scarce commodity in many parts of the world. Thus, available water resources need to become usefully exploited and fully utilized. In this respect, wastewater recycling is one of the effective means for improving the national water use efficiency. Reuse of wastewater for different
purposes is usually preceded by a reclamation process. These wastewater reclamation techniques vary widely from expensive relatively sophisticated units such as reverse osmosis plants to low cost biological and natural methods such as pond systems.

Agricultural drainage water can be a potential source of irrigation water. Reuse of agricultural drainage water is successfully adopted in many countries. The reuse strategies include direct application for irrigation or indirectly by assimilation into a fresh water body. However, if the agricultural drainage network is receiving domestic or industrial wastewater, direct or indirect reuse of the drainage water may create health hazards. In this case, the drainage water should undergo a certain level of water treatment using an appropriate technique for the vast amounts of water before it can be recycled into the system, Task report 1991.

This research work uses aeration weirs as a means for the spontaneous increase of dissolved oxygen (DO) which is a primary and comprehensive indicator of water quality in natural waters (McBride, 2002). In fact, when the DO concentration drops under acceptable values, aquatic ecosystem health could be seriously impaired and desirable uses of water resources could be precluded (Gulliver et al., 1998). A study on the effect of sanitary and industrial wastes disposal on the water quality of Rosetta Branch of River Nile (Egypt) near Kafr El-Zayat area in the Nile Delta using Qual2E model. The results indicated that the discharge of industrial as well as drainage wastewater into the Nile produce marked effects on the water quality especially at the mixing points (El-Bahrawy et al., 2002). Therefore, water quality standards and criteria for DO are provided by environmental regulation of many countries, such as the United States, the United Kingdom, Germany, and Japan, Italy and Egypt.

Egypt's Nile River water resource is under increasing stress due to increasing competition for available water. Irrigation needs are expanding, as are domestic and industrial water needs due to population and industrial growth. An increasing load of pollutants is threatening Egypt’s water quality, environment and the health of its citizens. The Ministry of Irrigation and Water Resources (MIWR) is the primary Egyptian government agency charged with the management of water resources and water quality.

**2- MODEL DESCRIPTION**

The experimental work was conducted in a 22.0 m long and 1.55 m wide flume. The flume was constructed on a plain concrete foundation and brick walls isolated and plastered with mortar. The flume is 2.75 m high in the first 7.0 m and the side walls height drops to 1.5 m in the rest of the flume. At the upstream side of the flume a sump was constructed to house the submersible pump used for circulating the flow. Water is returned back from the downstream of the weirs to the sump via a rectangular channel attached to the flume, thus the system operates in a closed circuit mode.

The sump and the flume were initially filled with water prior to operation. The maximum capacity of the pump used (P1) was 120 lit/sec. The flow was measured
using an ultrasonic flow measurement meter (F1), Figure (1). The flow rate was controlled using a sluice valve (V1) placed at the delivery side of the pumping unit. The sump has a storage capacity of 7.5 m$^3$ and during the operation of the flume the pump lifts the water to the upstream side of the weirs. The entrance of the flume is depressed with barriers so as to act as a slowdown chamber to reduce the pressure of the influent water prior to reaching the weirs. The flume was operated using a conventional weir.

3- EXPERIMENTAL OPERATIONAL PROCEDURE

The weir was placed at a distance of 6.60 meters from the beginning of the flume as shown in Figure (1). After each run oxygen was stripped from the water prior to the next run using a reducing agent. Sodium sulphite was added to the water at locations A, B, C and D as shown in Figure (1). 7.8 mg/lit of sodium sulphite were added to water to reduce the dissolved oxygen content by 1 mg/lit, Tebbut et al., 1977. After adding the chemical, the water was manually mixed to achieve homogeneity and two hours were allowed before starting another run to ensure that all the sodium sulphite was oxidized. Temperature was not controlled but was measured during each run according to the ambient shade temperature at the location of the flume.

Dissolved oxygen was measured for each run at points 1, 2, 3, 4, 5 and 6 as shown in the figure; on a time adjusted basis till it reached saturation. It was measured before the dosing of sodium sulphite and after two hours from dosing before the pump start-up. After the pump operation, the DO was measured every 15 minutes till it reached saturation level which was after about 60 to 120 minutes.

The drop height was varied by raising or lowering the weir to give the required drop height and it was measured as the difference between the upstream and downstream water levels. The height or depth of water at the downstream side of the weir (tail water depth) was controlled by the gate (W2) at the entrance of the sump.

Nine runs were conducted with the drop height varied for each run starting with a height of 0.6 m and ending with 1.4 m. The specific discharge was changed in each run from 0.016 to 0.075 m$^3$/sec.m yielding eight sub-runs in each run. The tail water depth was fixed to one thirds the drop height and it was only varied twice for one specific discharge in each run to find its effect on the aeration efficiency.

Each run or sub-run starts by adjusting the valve and weir at the end of each previous run or sub-run then the pump is shut-off and the DO measured before and after the reducing agent in the same sequence mentioned above. The dissolved oxygen concentration was measured at the six difference sampling locations indicated in Figure (1). During each sub-run and at the specific discharge under study, the dissolved oxygen concentration upstream the weir continuously increased as the rate of increase declined with time towards reaching the saturation level. (-120) minutes means just before the addition of the reducing agent and (0.0) minutes is after two hours of the addition and prior to pump start-up.
Fig. (1) Pilot setup using conventional weir
4- PERFORMANCE OF CONVENTIONAL WEIRS

4-1 Effect of drop height

The drop height was varied nine times for nine runs starting from 0.6 m to 1.4 m. The dissolved oxygen values were measured at intervals of fifteen minutes, thus giving seven pairs of measured dissolved oxygen concentrations upstream (C_u) and downstream (C_d) of the model. The saturated oxygen concentration (C_s) was calculated as follow:

\[ C_s = e^{-17.015355+0.0226297(T+237.15)+(3689.38l(T+273.15))+(0.0116-6.544l(273.15+T))} \]

The average aeration efficiency was calculated and adjusted to aeration efficiency at 15°C (E_{15}).

Based on the analysis of the experimental results, it was found that the mean of the adjusted values of E_{15} is an accurate representative for the whole set of data. Meanwhile, the uncertainty in every computed value of E_{15} was determined as the root of the mean square deviation from the individual records. Thus, the standard form of the aeration efficiency for each individual run was considered the mean value for the aeration efficiencies adjusted at 15°C and the standard deviation calculated.

From the figures, it can be noticed that the minimum aeration efficiency recorded was 13.09 ± 2.849 % at the lowest specific discharge under study. The values of the efficiency were increased by a value of (5-10) % by increasing the drop height by a value of 0.1m. But, however, from runs 7 to 9, this increase in aeration efficiency ceased and dropped to a range of (1-2) % as noticed in Figure (2).

![Figure (2) Aeration efficiencies at different drop heights](image-url)

Tail water depth=0.3×drop height
Weir width=1.2m
4-2 Effect of discharge

For each run representing a specific drop height, the discharge was varied eight times. The discharge was varied from 0.016 m³/sec.m to 0.075 m³/sec.m with step increase of 9×10⁻³ m³/sec.m. An average of 1% increase in aeration efficiency was recorded for each step increase of discharge at a fixed drop height with an overall average increase of (0-10) % for the whole run. Figure (3) shows a plot of the measured aeration efficiencies for each run at every specific discharge. From Figure (3), it can be noticed that the increase of aeration efficiency is low for lower specific discharges and slightly increases at specific discharge of 0.042, 0.05, 0.058 and 0.067 m³/sec.m represented by sub-runs 4, 5, 6 and 7.

After that, at the specific discharge of 0.075 m³/sec.m represented by sub-runs 8, the increase in aeration efficiency dropped and in some runs it was lower than that recorded for sub-run 7 as in runs 5 and 8.

![Figure (3) Aeration efficiencies at different specific discharges](image)

Tail water depth=0.3×drop height
Weir width=1.2m
w.h. =weir height

4-3 Effect of temperature

The system was monitored during the winter for a series of runs and sub-runs in order to determine the effect of temperature decrease on the aeration efficiency. The system was operated for runs number 2 to number 8 and in each run for sub-runs number 3 to 8 with all other parameters adjusted similar to those of the summer runs except for the temperature which was not controlled and was left depending on natural temperature prevailing in the winter season. Although oxygen saturation levels increased in winter.
due to the drop in temperature, the aeration efficiency decreased for the same set-up compared with the summer readings. Both summer and winter aeration efficiencies when reduced to the reference temperature of 15 °C gave almost similar values but with a difference of 1% or lower. But when demonstrating raw field data, a difference of about (3-8) % drop of aeration efficiency was recorded in winter compared with summer. Thus it can be noted that, in general, aeration efficiencies decreases with the decrease of water temperature although on the contrary the oxygen saturation temperature rises. This decrease in efficiency may be attributed to two reasons, firstly, the increased saturation concentration as the calculation of the aeration efficiency, is a function of the saturation concentration for the same upstream and downstream oxygen concentrations. Secondly, it may be due to the effect of temperature increase on the oxygen transfer rate at the air bubble / water interface. Figures (4) and (5) show a plot of raw data for the same setup with only change in temperature. The second figure represents a plot of the aeration profile conducted in winter.

![Figure (4) Effect of temperature on aeration efficiency at different drop heights](image-url)
4-4 Effect of tail water depth

According to what was documented in literature, the tail water depth was adjusted at a constant value of one third the drop height. Thus, all efficiencies recorded in this paper are at a tail water depth of one third the drop height although, however, the drop height was varied to one quarter the drop height and 0.7 the drop height for the seventh sub-run in each run in order assess the effect of the tail water depth on aeration efficiencies. The seventh sub-run was chosen for this analysis as it gave the optimum aeration efficiency compared with the remaining sub-runs at different specific discharges. Figure (6) demonstrates the aeration efficiencies obtained by varying the tail water depth.

By decreasing the tail water from 1/3 to 1/4 the drop, the aeration efficiency was found to decrease by a range of (2-10) %. But, however, increasing the tail water depth to 0.7 the drop a very slight or unnoticeable increase in aeration efficiencies was noticed and in some cases an aeration drop was recorded like in runs number 2, 8 and 9. Only run seven showed an increase of 3.66% which is odd compared to other runs and no any clear explanation to this increase was concluded.
Figure (6) Effect of tail water depth on aeration efficiency
w.h. = weir height q=0.067

Figure (7) Raw samples recorded data across the flume length for sub-run (1/7)
4-5 Effect of receiving pool length

Air bubbles floating on the surface of water downstream of the weir at the jet impact point contribute to the final aeration efficiency of the weir. Thus, sufficient length must be provided at the downstream of the weir to allow adequate water/air bubbles contact. The minimum required downstream length was calculated using the empirical formula developed by Nakasone, 1987. Figure (7) shows a sample of the dissolved oxygen readings recorded across the flume length for sub-run number (7). Readings (1) and (2) are upstream the weir and are almost equal due to the fact that no aeration takes place at these points. For each sub-run the dissolved oxygen was measured at intervals of 15 minute till or almost, the value of the saturation oxygen was reached or almost reached. In case of adopting this technique in the field, the effect of the receiving pool length is not of that much importance due to the fact that the drain length is quiet long and this issue will cease to provide any problems.

From this figure, the almost flat readings recorded at points (1), (2), (5) and (6) can be clearly noticed.

5- CONCLUSIONS AND RECOMMENDATIONS

1- The overall oxygen transfer efficiency was above average with a value of 58.12 ± 0.961. This was recorded at a drop height of 1.4 m and a specific discharge of 0.075 m$^3$/sec.m.

2- The increase in aeration efficiency between runs number (7) and (9) is about 4.43 ± 1.189 percent while, on the other hand, the aeration difference between runs number (7) and (1) is about 34.39 ± 1.234 percent. The high difference between these two aeration ratios is mainly due to the fact that at lower drop heights till 1.2 m a marked aeration efficiency is noted. Also increase of discharge has a direct impact on aeration increase.

3- The increase of temperature has a direct effect on the aeration efficiency. Values of the standard deviation calculated for each reading show a very slight deviation from the mean values recorded, the highest standard deviation value recorded was ± 8.428 while the lowest value was ± 0.100. The effect of the tail water depth on aeration efficiencies was negligible with some cases no any difference is recorded.

4- It is recommended to establish an in stream drainage water treatment system to improve the water quality in open agricultural drains receiving raw sewage for the sake of less risk disposal in surface water bodies or reuse for irrigation.

5- Practical weir design in nature should be flexible to account for the drop in aeration efficiency that may be associated with the temperature drop and the changes in organic load in terms of BOD; in order to maintain a fixed dissolved oxygen level in the stream across the year.

6- The major constraint and draw back for the proposed system was shown to be the lack of oxygen supply which can be compensated by the construction of high performance aeration weirs.
7- Modification in channel cross-section and slope may be made at the site of the proposed weir structure taking into account sufficient upstream and downstream lengths.

REFERENCES


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