EFFECT OF DISTRIBUTION NOZZLES ON TRICKLING FILTER PERFORMANCE

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ABSTRACT

The present study is an attempt to improve the trickling filter performance by enhancing both the oxygen transfer rate and wetting percent of the media surface; this was achieved using radial jet nozzle configuration instead of the conventional circular nozzle. The distributor-offset distance from the bed was taken into consideration as a geometric variable parameter. Two pilot-scale trickling filters were constructed on field to evaluate the effect of radial jet nozzle and offset distance on the trickling filter performance. Results indicated that the distribution system has major effects on the trickling filter performance, and that radial jet nozzle increased BOD removal ratio by approximately 10% higher than the conventional nozzle for fixed distributor and by approximately 7% for rotating distributor. Radial jet nozzle also enhanced DO% on the filter effluent for fixed distributor but not for the rotating one. The offset distance has approximately no effect on trickling filter performance. Increasing hydraulic loading rate reduced trickling filter efficiency, as the hydraulic retention time reduced.

Keywords: biological wastewater treatment; trickling filter; fixed film reactors; oxygen transfer rate; nozzle configuration; distributor arm; offset distance; biochemical oxygen demand; chemical oxygen demand; dissolved oxygen.

INTRODUCTION

Trickling Filters (TFs) are used in many wastewater treatment plants particularly for small and medium communities, the process is economic and reliable, but unfortunately BOD and suspended solids removal efficiency in many cases is not high enough to meet today’s effluent quality requirements. The present study aimed to enhance TF performance through enhancing the distribution system performance by applying Radial Jet Nozzle (RJN) configuration instead of the conventional circular nozzle and also by increasing the distributor offset distance (the distance between the distributor arm and the surface of the media). Radial jet nozzle is predicted to enhance Oxygen Transfer Rate (OTR) and to increase the wetting percent of the media surface.
Many studies stressed the importance of oxygen transfer rate on the TF efficiency; Larry and Clifford (1980) stated that in the outer portion of the biological slime layer, the organic material is degraded by aerobic microorganisms. The thickness of the aerobic zone is limited by the depth of oxygen penetration into the biofilm, which depends upon the coefficient of oxygen diffusivity in the biofilm, the concentration of oxygen at the biofilm-liquid interface, and the overall oxygen utilization rate of microorganisms present in the biofilm.

The supply of oxygen at the biofilm-liquid interface is either contributed by the Dissolved Oxygen (DO) content of the influent waste, or transferred from the air to the liquid film as the waste flows across the biofilm surface (Jank and Drynan, 1973).

To achieve the most efficient biological oxidation of the wastes, the two transport factors (oxygen transport and organic transport) must be sufficient high so that they do not impose a limit on the biochemical reaction (Mehta, et al., 1972).

Mehta, et al. (1972) in their study developed a model based on oxygen transfer as the limiting factor, and indicated that their mechanistic equation and the Velz type equations and NRC empirical equations have been shown to all reflect the same limiting factor, oxygen transport.

Williamson and McCarty (1976) demonstrated that at dissolved BOD$_5$ concentrations greater than about 40 mg/L, the TF would be flux limited by the dissolved oxygen and also substrate limited by the organics, so an increase in either DO or BOD concentrations will increase the organic utilization rate.

Vasel and Schrobiltgen (1991) calculated aeration efficiency on the TF when the support media was clean and when the biomass covered the media, and concluded that OTR is the limiting step of the process.

Based on experimental observations, Hinton and Stensel (1994) concluded that; oxygen availability controlled substrate and oxygen utilization rates, and they found also that increasing the hydraulic application rate increased OTR. Confirming that OTR controlled the substrate removal efficiency on TFs, Hinton and Stensel (1993) were also developed a mechanistic model based on oxygen consumption rate.

In filters packed with plastic media the maximum applied BOD$_u$ concentration determined, as being 400 mg/L seems appropriate for design purposes. When BOD$_u$ concentrations in excess of 500 to 600 mg/L are applied, OTR may become limited; the probability of odor production will also increase under these conditions (Schroeder and Tchobchanglous, 1976).

Although OTR seems to be the limiting factor in TF; generally the DO concentration is high in filter effluent, to explain this phenomena, Suschka (1987) suggested the two liquid layers concept most probably, one has to distinguish two liquid film layers, one “free” flowing over the other, “captured” liquid layer. The free liquid film contains very little biomass, thus has a relatively low oxygen uptake rate, this free flowing liquid film will be characterized by a high concentration of DO. While the captured
liquid film contains a large amount of biomass and thus has a relatively high oxygen uptake rate, but this captured film is characterized by lower oxygen concentration than the free film and oxygen concentration decreasing rapidly with film depth to zero. As a result the DO is limited at the liquid-biofilm interface, and being the controlling parameter in the process, while the filter effluent containing high DO concentration.

Results of WEF (1998) on the wetting efficiency indicated a real use of 40 to 50% for 89 and 135 m²/m³ cross flow media and similar levels for 89 m²/m³ vertical flow media, such results may lead to a reevaluation of configurations focused on improving the wetting efficiency, thus the used surface area. Another study of gravel at 114 m²/m³ and random media at 95 and 220 m²/m³ found that the wetting effectiveness decreased with increasing the surface area. Wetting effectiveness was found to be only 20 to 60%.

Sinkoff, et al. (1959) mentioned that; it was necessary to minimize the effect of uneven distribution, so the water was allowed to impinge upon an inverted funnel such that the flow was distributed in a circular ring on the top of the bed.

Maulik (1997) applied special nozzles having a flat spray pattern for fixed distribution systems, although such nozzles may improve the wastewater distribution over the media it could not enhance oxygen transfer rate.

In the present work, the effect of both different radial jet nozzle configurations and the offset distance on the TF performance was evaluated.

The effect of nozzle configurations and nozzle parameters (nozzle inner pipe diameter, jet exit velocity, offset distance, and opening thickness) on aeration efficiency was evaluated elsewhere (Ewida, et. al., 2004).

**EXPERIMENTAL TEST-RIG**

Two different RJN configurations were compared to the conventional nozzle. Figure (1) indicates the RJN configurations.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>N0</td>
<td>Conventional nozzle</td>
</tr>
<tr>
<td>N1</td>
<td>RJN, spray flow horizontally with 60mm plate diameter</td>
</tr>
<tr>
<td>N2</td>
<td>RJN, spray flow horizontally through slots at 45° from the plate’s radial direction</td>
</tr>
</tbody>
</table>

To achieve sufficient angular momentum for the distributor arm, the water was allowed to spread as a half radial jet through cutting the pipe diameter as shown in Fig. (1).

Effect of nozzle configuration and offset distance on the organic removal was evaluated utilizing two pilot-scale TFs that were constructed at EL-ASLOGY wastewater treatment plant, Zagazig, Egypt. Such plant treating municipal wastewater though the following units: screen, grit removal chamber, primary sedimentation, activated sludge units, final sedimentation, and sludge drying beds.
Radial jet nozzle

Conventional nozzle

Fig. (1) Nozzle configurations

- All dimensions in mm
- Drawing is not to scale
The utilized reactor for experimental work was fed with primary treated wastewater. A schematic illustration of the reactors was shown in Fig. (2), and a photographic picture of the reactors was shown in Photo (A.1).

The importance of pilot scale studies in research and development concerned with the treatment of sewage by trickling filters is now well established. Pilot scale filters are an effective compromise between bench scale and full-scale filters. They have advantages over the former in that being larger 1-12 m$^3$; they can be operated in the field actually in situ. Conventional grades of medium can be used, and because it would be impractical to supply filters of this size with artificial sewage then real sewage must be employed. The results of studies using pilot scale filters are more relevant to full-scale filter operation than those using bench scale filters housed in the laboratory (Gray and Learner, 1983).

Experimental Model Description

**Reactor body**, each reactor was constructed from steel plates 2mm thickness as a cylindrical barrel with 0.80m diameter and 2.50m depth.

**Medium support**, the medium was supported by a circular steel grid, which rested at 0.20m above the bottom of the filter. The grid was constructed in circular section using 40x10 mm steel strips. Such support is indicated in Photo (A.2).

**Ventilating ports**, eight ventilating ports each with 25mm diameter were distributed around the filter at 10cm above the filter bottom to allow good ventilation of the medium.

**Sampling ports**, sampling ports were constructed into the filter so that comprehensive analysis could be performed. Sampling ports enabled samples of sewage to be taken at 0, 0.45, 0.90, 1.35, 1.80m depths. Photo (A.2) shows a photographic picture of the sampling ports. Before the effluent samples were collected, each port was cleaned out and allowed to discharge for 10 min prior to sampling in order to flush out any dislodged materials.

**Filtering media**, The utilized media was gravel with effective size between 50-60mm; this size was selected as many authors recommended the stone size to be around 50mm. Christoulas, et.al. (1990) Conducted research using crushed stone medium of sizes around 50mm, and stated that this size of stone achieves for domestic sewage the best compromise between voidage and specific surface area. Gray and Learner (1983) held another study using 50mm slag furnace as a medium.

The media depth set to be 1.8m; which is within the range given in Metcalf and Eddy (1991) for both intermediate rate (1.25–2.5m) and high rate (1–2m) filters, also this depth is within the range given in WEF (1998) for high rate (0.9–2.4m) filter.

Gray and Learner (1983); and Vanhooren (2002) used in their work, pilot scale TFs with media depth of 1.8m. They stressed the importance of making the depth of pilot filters similar to that of full-scale filters. Contrary to the depth it is possible to
downscale the diameter, provided wall effects (hydraulic short circuit) remain negligible.

**Media preparation**, The media were screened using two sieves, one with dimensions 50x50mm and the other 60x60mm to select the gravel of size 50-60mm, the screened gravel contain some broken and flatted gravels that were removed, and so the final selected gravel was approximately round, as shown in Photo (A.3). The media were washed before installed on the pilot plants, and were installed carefully, to ensure that there is no gravels broke during installation.

**Fig. (2) Schematic illustration of the experimental test-rig**
To ensure similarity of the two pilot-scale filters equal volume of gravel (0.9 m$^3$) was placed in each filter. The gravel in each filter was counted to be approximately equal; each filter contains approximately 7000 gravel. The voidage (the volume of voids divided by the volume of solids) of filtering media was determined experimentally to be approximately 48%. This voidage was determined using water replacement method; the gravel was placed on a vessel with known volume and then this vessel was filled with water, the volume of water equal to the volume of voids.

**Pumping of wastewater to the reactors**, the pilot scale filters were fed with wastewater using two pumps; the first was one horsepower submersible pump, with 12m$^3$/hr capacity and 8m head. The second was 1.5 horsepower centrifugal dry installation pump, with 20m$^3$/hr capacity and 10m head. These two pumps were operated alternatively using time control system, to operate one pump for 15min while the other pump is in rest; the pump’s deliveries were directed to a constant head tank.

**Constant head tank**, Gray and Learner (1983) found that the fluid pressure in the pipes fluctuated because of variations in the power supply to the pump, so the pilot scale TFs were fed using constant head tank, which was made of steel and was installed above the reactors. The pumped wastewater was entered the tank through 25mm PVC pipes, and passed through a strainer with openings 3mm diameter approximately, to catch large particles that may escape from the primary sedimentation tank due to the poor performance of such tanks in EL-ASLOGY WWTP. The inlet strainer was cleaned daily and settled solids were flushed from the tank weekly. The two pilot scale TFs were feed through 25mm PVC pipes, provided with control valve to adjust the flow rate passed to the reactors. Above the feed pipes with about 0.20m, 50mm PVC pipe were installed to provide a by-pass for the excess wastewater.

**Reactor Startup and Operation**

All experiments were executed using primary treated wastewater from EL-ASLOGY WWTP. These experiments were conducted on the period from February to August during the year 2004. The influent wastewater to the pilot scale reactors has been characterized by measuring BOD$_5$, COD, PH, Temperature, total solids (TS) and total suspended solids (TSS). The primary treated wastewater characterization is indicated in Table (1).
Table (1) Primary treated wastewater characterization

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD₅ (mg/L)</td>
<td>163-210</td>
<td>186</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>337-451</td>
<td>393</td>
</tr>
<tr>
<td>pH</td>
<td>6.9-7.4</td>
<td>7.1</td>
</tr>
<tr>
<td>Temp. (°C)</td>
<td>22.6-29.3</td>
<td>24.6</td>
</tr>
<tr>
<td>TS (mg/L)</td>
<td>800-1200</td>
<td>1000</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>90-210</td>
<td>150</td>
</tr>
</tbody>
</table>

After the media were installed; the wastewater was allowed to spread over the media for three weeks as a start up period to develop the biofilm, after this period the first run was operated. The present work investigated mainly the distribution system, so the distribution of the wastewater over the media had been changed each run, therefore the start up period was repeated for each run to ensure that the biofilm is uniformly distributed and that the filter would be under steady state conditions.

With each change in the flow rate, a minimum period of three days was allowed to promote steady-state conditions during data collection (Hinton and Stensel, 1994), and then the samples were taken for five days to minimize sampling errors.

The samples were taken from the filter inlet to characterize the influent wastewater, and samples were taken from the filters effluent to measure the performance of each unit. To study the effect of filtering media depth, samples were taken at different depths of the filter.

Samples were taken from the filter effluent directly as the sedimentation tanks were not used in this study. As the wastewater characteristics are changing during the day, so the samples from the filter effluent and influent should be taken at the same time, which cannot be achieved when utilizing sedimentation tank; as the retention time of the TF equals few minutes while it is of the sedimentation tank equals 1.5-2hr. So the samples directly from filter effluent are more representative than after sedimentation tank.

The trickling filters effluent samples were taken to the Laboratory of the Environmental Engineering Department, Zagazig University, and then allowed to settle for 1hr, in a glass bottles to simulate the sedimentation tank. The actual sample for BOD₅ and COD analyses was the supernatant at the top of the bottle. The DO and temperature were measured in the site for samples directly taken from the pilot filters.

*Filter flushing*, hydraulic loading rate was increased to 70 m³/m²/d for 10 min daily in order to flush possible solid accumulation in the media. The pilot plant was visited twice a day to adjust flows, taking samples, and washing the media.
MEASUREMENT AND ANALYSIS

Filters influent and effluent samples were analyzed for; total BOD$_5$, total COD, T.S.S, and pH in the Laboratory of the Environmental Engineering Department, Zagazig University, while DO, temperature, and flow rate were measured on site.

RESULTS AND DISCUSSION

Effect of nozzle configuration on organic removal ratio (ORR), measured as BOD and COD removal ratios is introduced in the following sections, this effect was studied for the following items; Effect of RJN configuration (N2) compared to the conventional nozzle (N0) for fixed distribution system, Effect of nozzle offset distance, Effect of RJN configuration (N1) compared to the conventional nozzle (N0) for rotating distributor.

For all runs ORR versus the filter depth was introduced to investigate the effect of media depth on ORR and compare RJN to the conventional nozzle at different depths.

Effect of Nozzle Configuration for Fixed Distributor

The RJN configuration (N2) was compared to the conventional nozzle (N0), N2 was held on filter F2 and N0 was held on filter F1. The distribution nozzle in the two filters was maintained fixed. Selection of N2 for fixed distributor is due to such configuration achieved uniform distribution for fixed nozzle than dose N1.

Figure (3) shows a comparison between both of the ORR and effluent DO% for filter (F2) applying RJN configuration N2 and filter (F1) applying the conventional nozzle N0, at different three HLRs (17.28, 20.75, and 25.92 m$^3$/m$^2$/d). Filter F2 with configuration (N2) achieves higher BOD% than filter F1 with (N0); filter F2 achieved BOD% of 61.3, 58.8, and 52.4% at HLRs of 17.28, 20.75, and 25.92 m$^3$/m$^2$/d respectively, compared to 48.5, 46.6, and 43.8 % for filter F1. Also filter F2 gives higher COD% than filter F1, filter F2 achieved COD% of 49.75, 47.6, and 40.7%, compared to 34.2, 32.6, and 30.4 % for filter F1 respectively.

According to DO%, filter F2 gives better DO% values than filter F1 for all HLRs, the difference between the two filters in DO% increased with increasing HLR.

For ORR, the two filters have the same trend, as the HLR increased the liquid retention time decreased and so the ORR decreased.

The better performance of filter F2 with N2 than filter F1 with N0 may be due to two reasons: first: the RJN configuration N2 distributes the flow uniformly over the media, so every part of the media has the same hydraulic load, which enhances the wetting efficiency of the media that has a direct effect on increasing the filter efficiency. Second: the RJN configuration (N2) increases the initial DO% at the influent of the media; this may increase the aerobic zone of biofilm and result in increasing the filter efficiency.
Effect of Nozzle Offset Distance

The nozzle offset distance was evaluated for the conventional nozzle (N0), for filter F1 nozzle was held at constant distance H=30cm and for filter F2 nozzle was operated at three different offset distances (5, 30, 60cm), the distribution nozzles in the two filters were maintained fixed. Figure (4) shows the ORR and effluent DO% for different offset distances. Increasing H from 5 to 60cm increased ORR and DO% slightly, BOD% increased from 48.9 to 51% and COD% increased from 33.1 to 35.9% and also DO% increased from 33% to 36%. The poor effect of the offset distance on trickling filter efficiency may be due to; first: the offset distance does not affect the flow distribution, so does not affect the wetting efficiency. Second: the offset distance has a little effect on DO% as evaluated by Ewida et al., (2004).

Effect of offset distance for RJN was not evaluated, as increasing offset distance will change the radius of projected wetted area of the media so the change of filter performance will not be due to offset distance only.
Effect of Nozzle Configuration for Rotating Distributor

Radial jet nozzle configuration (N1) was compared to the conventional nozzle (N0), configuration N1 was held on filter F2 and N0 was held on filter F1. The two filters applied rotating distributor to increase the distribution efficiency. As for rotating arm any RJN configuration will achieve uniform distribution, configuration N1 was selected, as it is simple in manufacturing and does not require complicated machining.

Figure (5) shows a comparison between both the ORR and effluent DO% for filter F1 applying N0 and filter F2 applying N1 at three different HLRs (20.75, 25.92, and 31.1 m³/m²/d). Filter F2 with N1 achieved higher BOD% than filter F1 with N0, filter F2 achieved BOD% of (61, 56.5, and 52.9%) at HLRs of (20.75, 25.92, and 31.1 m³/m²/d) respectively, compared to (52, 49.8, and 45.9%) for filter F1. Also filter F2 gives higher COD% than filter F1, filter F2 achieved COD% of (45.8, 41.7, and 38.2%) at HLRs of (20.75, 25.92, and 31.1 m³/m²/d) respectively, compared to (36.1, 34.3, and 30.6%) for filter F1. The better performance of filter F2 with N1 than filter F1 with N0 may be due to; RJN configuration N1 distributes wastewater uniformly over the media so enhances the media wetting efficiency, also RJN enhances the initial DO% at the filter influent that may increase the aerobic zone of the biofilm, such two factors enhance the trickling filter efficiency.
Fig. (5) Effect of nozzle configuration for rotating distributor, at 165mg/L average influent BOD₅

According to DO%; filter F1 gives better DO% values than filter F2 for all HLRs. The DO% increased for both filters with HLR increase. The reason for increased DO% for filter F1 than for filter F2 can be explained according to; two liquid film layers. This may be due to that; RJN applied on filter F2 distributes wastewater uniformly over the media and so the liquid film thickness is less than that of filter F1, this facilitates the oxygen transfer and so increases the oxygen consumption rate by the biofilm, which results in the decrease of DO%, but in filter F1 the liquid film thickness is thicker so the free liquid is thick and rich with DO which can not penetrate the captured liquid layer and so the effluent has a more DO than filter F2. Such results on DO% indicated that oxygen concentration in bulk water would give little information, about the local oxygen concentration inside the biofilm (Sarner, 1986).

The two filters F2 with N1 and F1 with N0 have the same trend; as the HLR increased the liquid retention time decreased and so the ORR decreased.

Results on the filter depth indicated that, for the two pilot-scale trickling filters under all conditions; as the filter depth increased up to 1.8m, COD and BOD removal ratios increased with the highest removal ratio achieved in the first 45cm of the media.

Discussion of the Experimental Results

Applying the RJN configuration for fixed distributor enhanced the TF efficiency by approximately 13, 12, and 9% of BOD% at three different HLRs (17.28, 20.75, and 25.92 m³/m²/d) respectively. While applying RJN configuration for rotating
distributor enhanced the TF efficiency by approximately 9, 7, and 7% of BOD% at three different HLRs (20.75, 25.92, and 31.1 m$^3$/m$^2$/d) respectively.

Gray and learner (1984) enhanced the TF efficiency by approximately 6% by replacing the top 0.75m of 1.8m slag filter media with an equivalent depth of random plastic media, but stated that; the cost of modifying filters in this way are high, principally because random plastic media is more than twice the cost of blast furnace slag.

Analysis of results from over 100 wastewater treatment plants applying TF indicated that; conversion of a single-stage system to two-stage with the same quantity of media can be expected to greatly improve the TF efficiency by approximately 9%. Trickling filter efficiency could also be enhanced by approximately 10% by chemicals addition (such as ferric chloride and polymers) (Pierce D.M).

CONCLUSIONS

Main conclusions of the present study are:

1- Distribution system has a major effect on the trickling filter performance for high hydraulic loading rates.

2- Applying the RJN configuration for fixed distributor enhanced the TF efficiency by approximately 13, 12, and 9% of BOD% and by 15.6, 15, and 10.3% of COD% at three different HLRs (17.28, 20.75, and 25.92 m$^3$/m$^2$/d) respectively, also radial jet nozzle enhanced dissolved oxygen than the conventional nozzle at the filter effluent.

3- Applying RJN configuration for rotating distributor enhanced the TF efficiency by approximately 9, 7, and 7% of BOD% and by 10, 7.5, and 7.5% of COD% at three different HLRs (20.75, 25.92, and 31.1 m$^3$/m$^2$/d) respectively, while the radial jet nozzle achieves lower DO% than the conventional nozzle at the filter effluent, which means that filter effluent DO is meaning less and does not present the actual filter performance.

4- Increasing the nozzle offset distance for the conventional nozzle from 5 to 60cm increased COD and BOD removal ratios slightly. Also, it enhanced DO% by a little values, so it is not recommended to increase the offset distance in the conventional nozzles arrangements.

5- For the two pilot-scale trickling filters under all conditions; as the filter depth increased up to 1.8m, COD and BOD removal ratios increased with the highest removal ratio achieved in the first 45cm of the media.

6- Increasing the hydraulic loading rate, decreased COD and BOD removal ratios as the retention time decreased, while the effluent DO% increased.
REFERENCES


Pierce D.M. “Upgrading Trickling Filters” MCD-42, Report reviewed by the Environmental Protection Agency, Virginia, 22151.


Appendix (A)

Photo (A.1) Photographic illustration of the field exp. test-rig

Photo (A.2) medium support and sampling ports

Photo (A.3) rotating arm and the gravel media