FLOWFORMS AND PONDS IN ON-SITE WASTEWATER TREATMENT

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Abstract

Flowform cascades channel a downward-flowing stream of water in a pulsating figure-of-eight pathway. It has been suggested by flowform designers that passage through this flow path enhances the life-supporting properties of water. Flowforms were designed for and are commonly utilised as water features in artistic and aesthetic applications. Flowforms have also been utilised in a limited number of experimental on-site and cluster wastewater treatment systems since the 1970s. Recent years have seen a growing interest in their potential for use in a range of wastewater quality improvement applications including aeration, BOD reduction and disinfection. However, little or no work has been undertaken to date to quantify the effect of flowforms on DO, BOD and pathogen indicators. This paper describes a study on the effect of two flowform cascades on the quality of a number of effluent types. It was found that the flowforms increased the DO concentrations in low (roughly 10 mg/L) and medium (roughly 100 mg/L) BOD effluents, thus confirming reports of their suitability for reducing waste stabilisation pond odour. In the "near laboratory" conditions of this study, no significant reductions in BOD or faecal coliform concentrations were observed. It is suggested that further studies could examine the effect of flowforms on the disinfective power of established pond / flowform wastewater treatment systems.

Keywords

aeration, BOD reduction, disinfection, flowform, odour reduction, on-site, pond, wastewater treatment

1 Introduction

The beneficial effects of pond (or lagoon) detention on wastewater quality have long been recognised. Crites and Tchobanoglous (1998) identify three basic types of pond. These are aerobic (usually shallow and including artificially aerated lagoons); anaerobic (usually deep); and facultative or stabilisation ponds (of intermediate depth, typically 1 to 2 m, including aerobic and anaerobic zones). In large centralised sewage treatment systems, facultative ponds have traditionally been used to remove BOD and to achieve pathogen reduction. Reed *et al.* (1995) cite a number of studies which indicate that the removal of nutrients, particularly nitrogen, also occurs in ponds. The resurgence of suspended solids concentrations resulting from algal blooms in nutrient rich effluents is the major disadvantage of pond treatment. Another disadvantage is the long detention time required for complete treatment, necessitating a relatively large pond surface area. On the positive side ponds require low inputs of capital, energy and maintenance relative to other treatment approaches.

In Australia, there has been a recent move towards the use of ponds for post-treatment wet weather detention storage in both single dwelling and cluster on-site treatment systems. While tanks may be appropriate for this purpose in the single dwelling case, it is often more economical to use a pond in larger on-site situations. The following question then arises: "is further treatment occurring in the pond, and if so, how much?" A recent study by Headley and Davison (1999) of a 2,500 L/day (equivalent to about 6 households) reed bed wastewater treatment system found that significant reductions in nitrogen and faecal coliform concentrations occurred in the downstream detention pond. In this case disposal was by sub-surface land application and therefore the level of disinfection was not an issue. However, there is often a desire on the part of a householder or system manager for a level of "natural" disinfection that would permit above-ground disposal. In this case the question becomes: "how can the natural disinfective properties of ponds be augmented to achieve faecal coliform concentrations of less than the required (in NSW) 30 cfu/100ml?"

Flowforms are twin lobed (usually concrete) bowls which are arranged in cascades to facilitate the downward flow of water in a figure-of-eight pattern. According to Riegner & Wilkes (1988), they were "invented" in the early 1970s by English sculptor John Wilkes in his attempt to generate flow patterns for water which would 'enhance its life giving properties'. Trousdell (1989) suggests that the pulsating, figure-of-eight movement induced by the flowform promotes a 'revitalising function' in water, which he likens to a scaled-down version of the rhythmical effect of the natural water cycle. He also suggests that water which has been revitalised in a flowform will in turn revitalise those living organisms that utilise it. It is apparent that water receives a degree of aeration in tumbling down a flowform cascade. In addition it has been suggested that another side-effect of the action of flowforms on wastewater might be natural disinfection by solar ultra violet (UV) radiation. The question now becomes: "to what extent, if any, can the pond/flowform combination be used for disinfection and aeration of wastewaters?"

This paper attempts to briefly outline the history of flowforms with particular emphasis on their potential application to wastewater treatment. It also reports on a study into the effects of two models of flowform on the concentrations of dissolved oxygen, biochemical oxygen demand and faecal coliform levels in high and low BOD wastewaters. A brief review of some recent theories on the disinfective processes in ponds is also presented.

2 Flowforms

In the three decades since John Wilkes created the first flowforms, several dozen variations on the initial design have been developed. While some models have been created specifically for their artistic and aesthetic appeal, others have been used for oxygenation of water and for the stirring of biodynamic preparations (Trousdell, 1989). Flowforms have been used artistically as dynamic sculptures in schools, landscapes, banks, malls and gardens in many parts of the world, receiving positive comments from artists and the public alike (Riegner & Wilkes, 1988). Pursuing this theme, in delivering the keynote lecture to the Second International Conference on Ecological Engineering for Wastewater Treatment, J.S. Davis (1996) discusses the effect of "subtle energies" on water and suggests that "the type of movement made by water along a [flowform] cascade seems to be the significant parameter in changing certain characteristics of water." He also suggests that the fact that we no longer have water so visibly around us has decreased our awareness of it in general. On this latter point, Trousdell (1989) claims that creative landscaping with flowforms for private and public situations has repeatedly brought a sense of enlivened well-being through the flowform sculpture and its rhythmic water phenomena. Expanding this point, Wilkes believes that the aesthetic effect demonstrated by flowforms is of the utmost importance for a reawakening of our consciousness and conscience for water, and that flowforms can draw people's attention to water as a vital force in the environment (Riegner & Wilkes, 1989).

In an attempt to quantify the effect of the flowform's rhythmical motion on water, Mansvelt (1986) conducted a four year research project which compared the effects of a flowform-three-pond system with a stepped-cascade-three-pond system running in parallel. He states that although qualitative differences were noted in the fauna and flora which colonised the two pond systems, no consistent differences were found between the physico-chemical water quality parameters. Although little quantitative work appears to have been done on the effect of flowforms on standard water quality indicators, they have been utilised in cluster on-site wastewater treatment systems in Europe since the 1970's. In 1973, a seven pond system incorporating three flowform cascades was installed to treat the wastewater from the 200 students and staff at the Rudolph Steiner school at Jarna, Sweden. The school's previous sewage treatment system consisted of a single pond, which produced intolerable smells and an unsightly scum layer in summer (Bunyard, 1978). Carde (1990) states that two flowform cascades are now installed on the first pond, into which the raw sewage is discharged, and one on the fourth pond. Carde quotes the manager of the treatment system as stating that the installation of the flowforms on the first pond reduced the required residence time of the wastewater in it from three months to one week, and removed the unpleasant smell associated with the previous single pond treatment system. Olsson & Wells (1986) state that the circulation of the wastewater from the pond bottom to the flowforms results in "removal of bad smelling gases" in the anaerobic bottom layer, increases pH and oxygenates the wastewater. These authors also state that the treatment system was able to reduce BOD_7 from 105 to 26 mg/L, and phosphorous from 8.6 to 4.7 mg/L , from the first pond to the last pond. In addition, total nitrogen concentration was reduced from the influent level of 5.5 mg/L to an effluent concentration of 3.2 mg/L. Gee (1980) states that the Jarna sewage treatment system has also become a haven of artistic and natural beauty, as residents and visitors alike can stroll through the park and see beautiful sculpture, the intricate, swirling patterns of water cascades, ponds, plants and wildlife. Following the establishment of the Jarna system, flowforms have been utilised in other on-site wastewater treatment systems in Europe and Australia.

It has been suggested that one of the side effects of passage of wastewater down a flowform cascade might be the reduction of pathogens via the bactericidal effect of incident solar UV radiation. While no data existed prior to the present study to either support or refute this suggestion, there are numerous references in the literature on constructed wetland and lagoon treatment systems to the fact that solar UV radiation plays an important role in the pathogen reduction capabilities of these treatment methods (Kadlec & Knight, 1996). Therefore it has been widely assumed that the presence of a flowform cascade in a wastewater treatment system would enhance UV exposure and hence the level of disinfection achieved. While studies have been undertaken on the disinfective capability of whole systems incorporating ponds, wetlands and flowforms, none appear to have been implemented on flowform cascades alone. The study described below was an attempt:

- to determine the extent of disinfection; and
- to quantify the level of oxygenation (and consequent BOD reduction, if any)

resulting from the passage of wastewater down a flowform cascade.

3 Methods

The trials, using an eight bowl Jarna and a three bowl Miroma cascade, were conducted between June and September of 1998 on a rural property near Lismore in northern New South Wales. Three separate trials were conducted:

- the pilot tests - to determine optimal flow rates and experiment duration;
- the replicate tests - to provide a replicate data set for statistical analysis; and
- the large scale tests (Jarna model only) - to determine the effect of the flowforms on a body of water larger than had been used in the pilot and replicate trials.

For the pilot and replicate trials two different types of flowform cascade were set up outdoors, immediately adjacent to each other, with effluent discharging from the bottom bowl of each cascade into a 200 L sump. Recirculation was by pump to the top of the cascade. Two effluents, secondary treated greywater (BOD 10 - 20 mg/L) and dairy effluent (BOD 80 - 150 mg/L) were used. The pilot tests were used to determine the most appropriate flow rates and trial durations for the subsequent replicate tests. Consequently the replicate tests were run for three hours at flow rates of 50 L/min. (Jarna) and 100 L/min. (Miroma). In-field measurements utilising a Horiba model U10 multiprobe included dissolved oxygen (DO), pH, temperature, conductivity, and turbidity. Treated effluent samples were collected for determination of BOD and faecal coliform levels at the Southern Cross University Environmental Analysis Laboratory, according to the methods specified in Lancaster and Twigg (1996). Analyses of covariance were undertaken on each of the dependent water quality variables in the replicate data set, using the SPSS statistical analysis software package. Further information about this analysis is provided in Brown (1998). In the large scale tests a 2000 L tank replaced the 200L sump on the Jarna cascade. Two 24 hour trials were conducted on low (24 mg/L) and high (1070 mg/L) BOD wastewaters.

4 Results

4.1 Dissolved Oxygen

Table 1 shows mean DO concentrations at various times after pump startup. Columns C and D show that the DO levels had increased appreciably after 10 minutes from the start of the trial. This period would represent an average of 5 passages down the cascade for the Miromas and 2.5 passages for the Jarnas. Of particular interest is the fact that the DO concentration in the Miroma dairy effluent ROSE to its final level of 8 mg/L in only 10 minutes and was still AT almost 6 mg/L ONE hour after the pump was switched off. For both types of effluent, the Miroma cascade achieved higher final DO levels (8.7 vs. 8.6 mg/L for greywater, and 8 vs. 7.15 mg/L for dairy - column E) suggesting better aeration performance for this model. It should be pointed out however that the test effluents used in the Miromas were of a lower BOD than those used for the Jarnas (column B). Therefore no conclusion about the relative aerating efficiencies of the two flowform models can be drawn from this data.

Table 1: Mean dissolved oxygen concentrations (mg/L) for the two flowform models at various stages of the three hour replicate tests on dairy effluent and greywater (G.W.).

Flowform / Effluent		Initial BOD mg/L	DO (mg/L) at time in minutes after "pump on"				
			0 pump on	**10**	**180** pump off	**190**	**240**
(A)	n	(B)	(C)	(D)	(E)	(F)	(G)
Jarna / dairy	2	147	1.75	5.95	7.15	4.75	2.5
Jarna / G.W.**	4	9.2	4.45	7.75	8.6	6.7	*
Miroma / dairy	3	77.4	2.8	8	8	6.3	5.97
Miroma / G.W.	4	6.35	5.13	8.3	8.7	6.55	*

* data not collected ** G.W. = greywater

The low BOD (24 mg/L) large scale test resulted in a steady increase in DO concentration from 1.6 mg/L to 8.0 mg/L during the first eight hours (12 complete turnovers of the tank contents) of the experiment. This elevated DO level fell 3 mg/L, from 8.2 mg/L to 5.2 mg/L, in the two hours following shutdown. In the second large scale test a high BOD (1070 mg/L) effluent was created by mixing cheese whey with greywater immediately prior to the test. The DO was observed to increase from 3.03 mg/L to 4.8 mg/L after the first four hours, then undergo a rapid decrease to an equilibrium level of 1.6 mg/L in the following two hours. This level of dissolved oxygen was maintained for the remainder of the experiment, and for the two hours following shutdown.

4.2 Biochemical oxygen demand (BOD)

Of the twenty-four replicate trials only four resulted in a BOD reduction. As shown in Table 2 an overall increase in BOD occurred for each of the four combinations of flowform model and effluent type. However, the large scale tests produced BOD reductions of 8% (from 24 to 22 mg/L) and 21% (from 1070 to 848 mg/L) for the low and high BOD effluents respectively.

4.3 Faecal coliforms

Out of a total of 24 tests, the replicate tests resulted in thirteen increases in faecal coliform counts, and only ten faecal coliform reductions. Table 3 shows that both the Jarna and Miroma flowforms produced overall mean faecal coliform increases when treating the greywater (61% and 114% respectively). These increases were of a larger magnitude than the overall mean decreases achieved by both models when treating the diary effluent (15% and 17% respectively). The low BOD large scale test resulted in a marginal (4%) decrease in faecal coliform levels, from 13 400 to 12 800 CFU/100ml. Useable data was not obtained for the high BOD test.

Table 2: Summary of BOD results for the 24 replicate three hour tests.

	DAIRY	GREYWATER
JARNA	n = 6 number of increases = 4 mean value increase = 17.6 mg/L number of decreases = 2 mean value decrease = 34.75 mg/L **Overall, there was a mean BOD increase of 0.15 mg/L.**	n = 6 number of increases = 5 mean value increase = 3 mg/L number of decreases = 1 mean value decrease = 3 mg/L **Overall, there was a mean BOD increase of 2 mg/L.**
MIROMA	n = 6 number of increases = 5 mean value increase = 8.84 mg/L number of decreases = 1 mean value decrease = 16 mg/L **Overall, there was a mean BOD increase of 4.7 mg/L.**	n = 6 number of increases = 6 mean value increase = 3.38 mg/L number of decreases = 0 mean value decrease = N/A **Overall, there was a mean BOD increase of 3.38 mg/L.**

Table 3: Summary of faecal coliform count results for the 24 replicate three hour tests.

	DAIRY	GREYWATER
JARNA	n = 6 number of increases = 2 mean value increase = 14% number of decreases = 4 mean value decrease = 30% **Overall, there was a mean decrease of 15% in cfu/100mL.**	n = 5 number of increases = 4 mean value increase = 82.75% number of decreases = 1 mean value decrease = 25% **Overall, there was a mean increase of 61% in cfu/100mL.**
MIROMA	n = 6 number of increases = 2 mean value increase = 49.5% number of decreases = 4 mean value decrease = 50.25% **Overall, there was a mean decrease of 17% in cfu/100mL.**	n = 6 number of increases = 5 mean value increase = 147% number of decreases = 1 mean value decrease = 50% **Overall, there was a mean increase of 114% in cfu/100mL.**

5 Discussion

As expected, the capacity of these flowforms to aerate wastewaters was found to be inversely related to the BOD of the effluent being treated. In the extreme case provided by the large scale high BOD test, the flowforms failed to elevate DO from its untreated base concentration of 1.6 mg/L, suggesting that air introduced to the effluent during passage down the cascade was immediately consumed by aerobic micro-organisms. The increased DO levels measured in all of the lower BOD effluents, post flowform treatment, confirms the role of flowforms for aeration and odour reduction in wastewater lagoons. In a recent project at a chicken abattoir at Byron Bay, NSW, three seven-bowl sets of Vortex flowforms (250 L/min) were used to treat a 2700 m^3 anaerobic pond that had been subject to chronic odour problems. An 80% reduction in odour levels was achieved *(pers. comm.* D. Pont, environmental consultant). There are other examples on the NSW north coast of flowforms being used on wastewater storage ponds from single dwelling to small town sized systems. Some interest in the use of flowforms as aeration devices on aquaculture systems has also been shown, in part because of their reputed life enhancing properties. While questions remain as to whether flowforms are the most economical or convenient way to achieve the required level of aeration in such situations, it is clear that they will continue to be used for the aesthetic and subtle reasons mentioned earlier. Meanwhile, more work is required before the aeration performance of a given model of flowform can be predicted with any confidence.

The BOD results present an interesting contrast between the replicate tests, which showed an overall increase, and the large scale tests, which both showed a BOD decrease. This was particularly marked in the case of the high BOD solution in which the BOD dropped 21% during the 24 hour trial. It is probable that the more quiescent conditions of the large tank (turnover time 40 minutes) provided a more favourable environment for carbon-consuming suspended growth micro-organisms than the smaller tank used in the replicate tests (turnover time 4 minutes). Because the DO in the test effluent remained at 1.6 mg/L (once equilibrium had been reached) it is most likely that the BOD reduction was largely the result of anaerobic activity and hence not attributable to the flowforms.

The lack of faecal coliform reduction noted in the trials clearly indicates that flowforms on their own cannot be regarded as a useful disinfection technology. One interesting feature of the results in Table 3 is that both dairy effluent results (turbidity > 1,000 FTU) showed faecal coliform reductions while the less turbid (15 < turbidity < 100 FTU) greywater results both showed faecal coliform increases. This result is in direct contrast to what would be expected if (as had been anticipated) direct kill by incident UV radiation was the most significant disinfective factor. UWRAA (1999) report that a similar unexpected result occurred when a pond with 60% duckweed cover achieved greater faecal coliform reduction (86%) than an uncovered control pond (62%). Pearson *et al.* (1987) point out that wastewater stabilisation ponds are particularly efficient at pathogen removal compared to other treatment approaches, and experience has shown that flowforms are generally used in conjunction with ponds. The question now becomes: "can a set of flowforms be used to enhance the disinfective properties of ponds, and if so, how?"

The main factors commonly described as influencing the disinfection capabilities of sewage treatment ponds are pH, number of ponds, depth of pond, mixing characteristics, light intensity, detention time, temperature, dissolved oxygen concentration, aggregation and sedimentation, and the release of toxins by algae (Fernandez *et al*., 1992; Gross, 1995). While the theories explaining the precise mechanisms controlling pathogen die-off in waste stabilisation ponds are in many cases only tentative (Mara & Pearson, 1986) many authors on the subject agree that light intensity is an important factor (Moeller & Calkins, 1980; Saqqar & Pescod, 1992). Three major theories emerge from the literature:

- direct inhibition of DNA replication caused by the UV portion of the spectrum;
- photosynthetically induced pH change; and
- photochemical damage in the presence of high pH and high DO levels (photooxidation).

The first mentioned and, because of its simplicity, most appealing theory is the principle by which artificial UV disinfection lamps operate. Pilkington (1995), however points out that many factors including turbidity and high bacterial loadings, as found in a stabilisation pond, create less than optimal conditions for this process. The findings of the present study and UWRAA (1999) also highlight the apparent inadequacy of this theory. The second theory is based on the fact that algal photosynthesis in ponds is one of a number of processes which results in the elevation of pH levels beyond the range of pathogen tolerance. Pearson *et al.* (1987) found this to be a major factor causing faecal coliform death in ponds. In relation to the third theory, Sinton *et al.* (1994) suggest that photochemical damage occurs when sunlight is absorbed by a sensitiser, which enters an excited state and initiates damaging reactions. Photosensitised reactions at the wavelengths found in sunlight are usually more injurious in the presence of oxygen, from which the excited sensitiser may form a number of reactive species, including singlet oxygen and hydrogen peroxide. The resulting cell damage is termed photooxidation. In their study of this process in waste stabilisation pond water, Curtis *et al*., (1992a) found that sewage-derived humic substances were the principal sensitisers, and that light effects interacted synergistically with elevated pH to increase the damage. They suggested that the process was completely dependent on oxygen, and that the rate of damage was proportional to the oxygen concentration. Curtis (1992b) therefore suggests that visible light is more important than UV, and that to have an impact on pathogen levels it must be complemented by high DO concentrations and pH levels.

It is therefore suggested that future studies into the role of flowforms in on-site system disinfection be performed on real world situations including an open pond (rather than the small tanks used in the current study), and that pH, DO and algal biomass levels be monitored.

6 Conclusions and Recommendations

The two models of flowform tested were found to be effective at increasing dissolved oxygen levels in both the dairy and greywater effluents. This finding is in accord with reports of odour reduction in ponds subjected to treatment by flowform cascades. Although the Miroma flowforms appeared to exhibit greater oxygenating ability than the Jarna model, the apparent difference in performance may have been a result of bias due to differences in the BOD of the test effluents. There was no increase in DO concentration in the large high BOD trial, indicating that there are limitations to the loadings (strength x volume) of effluent that can be effectively aerated by a given model of flowform. Further work would be needed to quantify the loading capabilities of the various models of flowform currently in use.

The flowforms tested demonstrated no capability for reducing BOD in the test effluents under the conditions of the trial.

The disinfective power of the flowforms under the test conditions was found to be negligible.

Because of their aesthetic appeal and their reputed effect on water's life giving properties, flowforms will probably continue to be incorporated into small on-site wastewater treatment systems. It is suggested that further studies be done on the effect of flowforms on the quality of wastewater in the storage ponds of such "real world" systems. In the light of the above discussion on disinfection processes in ponds it would be interesting to study the effect of a flowform cascade on the complex relationship between DO, pH, solar radiation and pathogen survival in such a pond.

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