PERFORMANCE EVALUATION OF ON-SITE AERATED WASTEWATER TREATMENT SYSTEMS

Peter Beavers, Ian Tully and Anne Woolley
Department of Natural Resources, Queensland

Abstract

Several studies have been undertaken in Australia and the United States to evaluate the field performance of aerated wastewater treatment plants and sand filters. In this study, it was found that 32% of plants tested complied with the three approval criteria, ie. Biochemical Oxygen Demand (BOD), Suspended Solids (SS) and Thermotolerant Coliforms (TC), 42% complied with BOD and SS, and 69% with TC alone. Inadequate or improper maintenance was identified as a main contributor to poor performance. The most common mechanical problem was the failure of the chlorination system through jamming of the tablets in the dispenser. The basic design of an AWTS system provides no barrier to excess suspended solids carryover from chamber to chamber. High-suspended solids concentrations in the final effluent were a common occurrence. Effluent from well-maintained systems generally complied with standards. Based on the results of this study, potential design modifications, improved maintenance procedures and monitoring parameters are suggested.

Keywords

aerated, biochemical oxygen demand, disinfection, performance, suspended solids, thermotolerant coliforms, treatment, wastewater

1 Introduction

Domestic on-site aerated wastewater treatment plants (AWTS) were initially approved for use in Queensland in 1987. Since their introduction there has been a rapid upsurge in installations in unsewered areas. Householders see advantages and resource savings with the ability to surface dispose of effluent.

The Department of Natural Resources, under the Standard Sewerage Law (subordinate legislation to the Sewerage and Water Supply Act, 1949) has responsibility for approving on-site sewage treatment plants having a peak design capacity to treat sewage of less than 20 equivalent persons. The performance evaluation procedures were formulated in 1987 with little knowledge about long term operation of the plants and only a short period of experience was available from the southern states. In 1994, it was decided that the long-term performance of the AWTS was in need of investigation because several local governments expressed concern over the quality of the effluent being discharged.

About the same time similar investigations into the long term performance of the AWTS were being undertaken in New South Wales by Campbelltown City Council (Rogers, 1994), New South Wales Health Department (Langhorne *et.al*., 1995), Western Australia Health Department (Devine and Waterhouse, 1997) and Khalife and Dharmappa, (1996).

Problems revealed from these investigations include inadequate capture of solids within the system, lack of appropriate maintenance, non-compliance with performance criteria from mechanically sound systems, servicing of AWTS not satisfactory and irrigation areas did not comply with guidelines.

Numerous field studies have been performed on on-site aerobic package treatment systems over the past 30 years in the United States (Asbury and Hendrickson, 1982; Brewer *et.al.*, 1978; Hutzler *et.al.*, 1978, Waldorf, 1978; Weignann, 1991, Hanna, *et. al*., 1995). The results of these studies often showed poor performance of the systems. Problems identified include maintenance and mechanical failures, as well as poor effluent quality from mechanically sound systems.

The objectives of this study were to evaluate the AWTS and intermittent sand filter field performance; compare the final effluent quality against the Department of Natural Resources standards; relate AWTS performance to system design, operation and maintenance; and develop suitable criteria to monitor field performance. This paper presents a summary of the analysis of collected data.

2 Methods and Materials

A database of installed AWTS and sand filters was prepared from information supplied by Local Government. This database was used to determine a statistically valid number of AWTS and sand filters to be field monitored for performance. Local Government was also approached to provide results from testing programs that they had undertaken. These data were unsuitable for inclusion in this study due to inconsistencies in sample collection locations and analysis parameters.

Nine models of AWTS and one aerobic sand filter were selected for monitoring during the study. The selection was based on the number of models that had been installed for 12 months or longer in a private dwelling in Queensland. The number of plants of each model monitored was determined on a statistical basis. The ten models were considered a good representative sample of all installed plants at the commencement of the study. The aerobic sand filter was included because of its increasing popularity as a viable alternative to an AWTS.

The initial proposal was to monitor 480 AWTS's and aerobic sand filters throughout as much of Queensland as possible. With all the resources available it was anticipated that the study would take three years to complete. Restrictions on the availability of the laboratory to carry out testing also contributed to the extended time of the study. After two year's progress, reductions in financial and human resources, a review of project aims and methods became necessary. The overall number of plants that could be monitored was reduced but still allowed the study to remain credible. A summary of plants monitored is shown in Table 1.

Monitoring of the plants was conducted in two separate programs.

Program A consisted of comprehensively monitoring 54 plants, six plants from each nine models. Six discrete samples were collected from each of the 54 plants. The samples were collected during peak morning and evening flows using an automatic sampler.

Program B consisted of collecting a grab sample from each of 162 plants of the 10 models. One test result from each of the plants in Program A was analysed with results of Program B.

Table 1: Summary of model selected and number of plants monitored

Manufacturer	Model	Plants Monitored
Biocycle (Qld) Pty Ltd	4700	29
Biocycle (Qld) Pty Ltd	5100	16
Biocycle (Qld) Pty Ltd	6000	23
Envirocycle Pty Ltd	MK6	16
Enviroflow Waste Water Treatment	Bio Filter	16
Envirotech Treatment Systems	Aerobic Sand Filter	16
S.B. Engineering Pty Ltd	Aqua Nova 2000	36
Septech Industries Pty Ltd	Turbo Jet 3000	10
Suncoast Waste Water Management	AL4600	16
Taylex Sales Pty Ltd	Clearwater 90	38

One sample was collected from the outlet of the secondary clarifier and analysed for BOD and SS. The surface of the secondary clarifier is recognised as the completion of the sewage treatment process.

One sample was collected from the first sprinkler and analysed for thermotolerant coliforms (TC). This location was selected closely following the chlorine retention/pump out tank.

An inspection of all plants visited was carried out to assess the operation of the plant and the condition of all components. The following on-site tests were carried out:

- Dissolved oxygen (DO) in the aeration tank measured approximately 200 mm below the surface at the outlet. On extended aeration plants the DO was measured near the end of an aeration cycle.
- Temperature in the aeration tank at same locations as DO measurements.
- pH of aeration tank adjacent to the outlet at the surface. pH of effluent sample was also recorded during laboratory testing.
- Clarity test used by servicing agents to indicate plant performance.
- Observations of colour, odour and any scums in aeration, secondary sedimentation, chlorine retention and pump out tanks.
- Chlorine residual (free and total) measured at the first sprinkler.

3 Results

No significant difference (at 5% level) was found between the results for BOD and SS for samples collected during peak flow periods (Program A) and grab samples (Program B) for all models tested. The following results and discussion on performance are based on grab samples collected under Program B.

The average quality of effluent (ex the secondary clarifier) for BOD and SS for the various models is summarised in Table 2**.** (Model Code in Table 2 does not correspond with model identification in Table 1). Bacteriological quality, based on TC in samples collected from the first sprinkler is summarised in Table 3. As quantification of the TC data was inconsistent during the trial (eg some results reported as >80 cfu/100mL, >800 cfu/100mL), data have been summarised on a cumulative frequency basis to allow assessment against TC guidelines for approval and various other effluent re-use options.

Table 2: BOD and SS in secondary clarifier effluent from AWTS and sand filter systems

		No of	BOD, mg/L				Suspended solids, mg/L			
Model	Process	samples	mean	S.D.	min	max	mean	S.D.	min	max
A	AS	29	44	68	8	370	76	210	5	1150
B	AS	16	38	40	9	150	174	581	4	2350
C	AS	23	39	24	7	90	43	45	5	160
D	AS	16	40	68	3	225	91	209	5	840
E	AS	38	48	35	1	120	35	32	5	120
F	AS	36	21	26	1	120	46	112	5	620
G	AS	10	46	30	3	100	46	50	5	140
H	EA	16	29	21	1	81	159	281	3	1110
I	Biofilter	16	33	44	4	190	24	16	5	55
J	Sand Filter	16	6	12	1	48	9	10	5	40
All		216	35	42	1	370	65	206	3	2350

3.1 Compliance with Approval Criteria

Overall, 32% of plants tested complied with all three of the approval criteria, that is BOD 20mg/L, SS 30mg/L and TC <1000 cfu/100mL (Table 4**)**. Forty-two percent of plants complied with both BOD and SS criteria, 45% with BOD alone, 67% with SS alone and 69% with TC alone (Table 3). The distribution of BOD and SS data for all plants tested (Figure 1) indicates 80 percentile values of 50 mg/L for both BOD and SS.

The general distribution of thermotolerant coliforms as shown in Figure 2 was similar for all models tested. The combined data for all models showed that the number of organisms was generally less than 100 cfu/100mL or greater than 1000 cfu/100mL indicating that disinfection was either effective or not effective.

Table 3: TC in effluent (1st sprinkler) from AWTS and sand filter systems

Model	Process	No. of Samples	Cumulative frequency of samples					
			<10 cfu/100mL#		<150 cfu/100mL##		<1000 cfu/100mL###	
			No.	%	No.	%	No.	%
A	AS	29	10	34	15	52	17	59
B	AS	16	6	38	8	50	8	50
C	AS	18	11	61	11	61	14	78
D	AS	15	7	47	11	73	12	80
E	AS	36	11	31	15	42	23	64
F	AS	29	17	59	21	72	24	83
G	AS	10	1	10	3	30	5	50
H	EA	14	8	57	11	79	12	86
I	Biofilter	16	8	50	9	56	12	75
J	Sand Filter*	14	3	21	6	43	9	64
All		197	82	42	110	56	136	69

*Effluent not chlorinated
Class A water (DNR, 1996)
Class B water (DNR 1996)
Approval criteria for AWTS; Class C water (DNR, 1996)

Table 4: Compliance of on-site aerobic wastewater treatment systems with approval criteria of BOD 20 mg/L, SS 30 mg/L and TC <1000 cfu/100mL

Model	Process	No. of Samples	Compliance with criteria for:							
			BOD, SS, TC		BOD, SS		BOD		SS	
			No.	%	No.	%	No.	%	No.	%
A	AS	29	6	21	9	31	10	35	18	62
B	AS	16	5	31	5	31	7	44	8	50
C	AS	23	7	30	7	30	7	30	14	61
D	AS	16	7	44	8	50	9	56	11	69
E	AS	38	7	18	9	24	10	26	21	55
F	AS	36	17	47	24	67	26	72	30	83
G	AS	10	1	10	2	20	2	20	6	60
H	EA	16	4	25	5	31	6	38	9	56
I	Biofilter	16	6	38	6	38	6	38	12	75
J	Sand Filter	16	9	56	15	94	15	94	15	94
Total		216	69	32	90	42	98	45	144	67

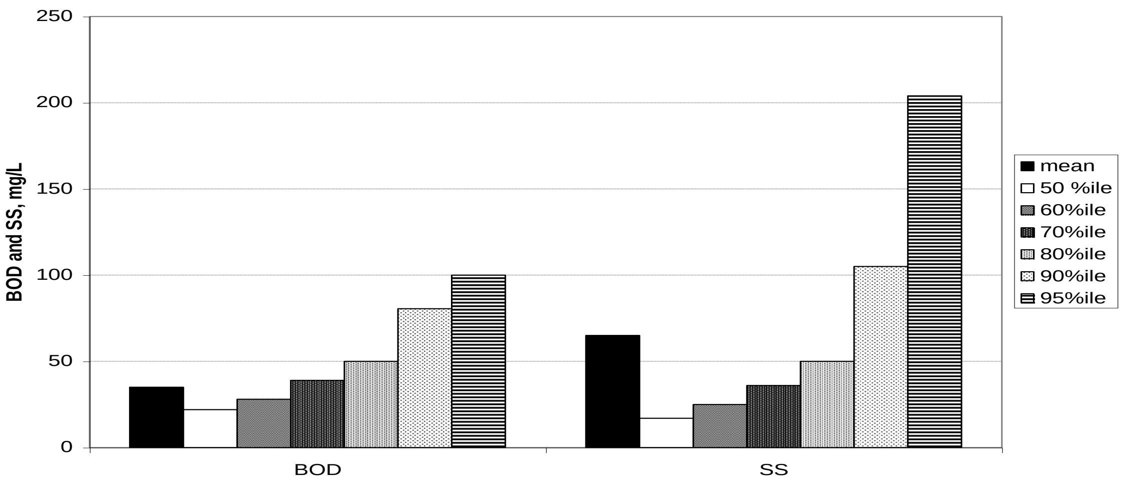

Figure 1: Percentile distribution of BOD and SS for combined data for all plants.

3.2 Process Comparison

The performance data for BOD and SS for all plants tested are summarised on a process basis in Table 5. For the activated sludge process there was no significant difference (5% level) detected between the seven models for either BOD or SS.

The sand filter process has generally performed better than the other processes for both BOD and SS removal. The average BOD of the sand filter effluent (6 ± 12 mg/L) was significantly different from that of the activated sludge, extended aeration and biofilter effluents with the latter three processes not significantly different from each other (5% level). While the data suggests that the processes performed best in the order of sand filter > biofilter > activated sludge > extended aeration for SS removal, the apparent differences were not significant (at the 5% level) being masked by the "within process" variability of the data.

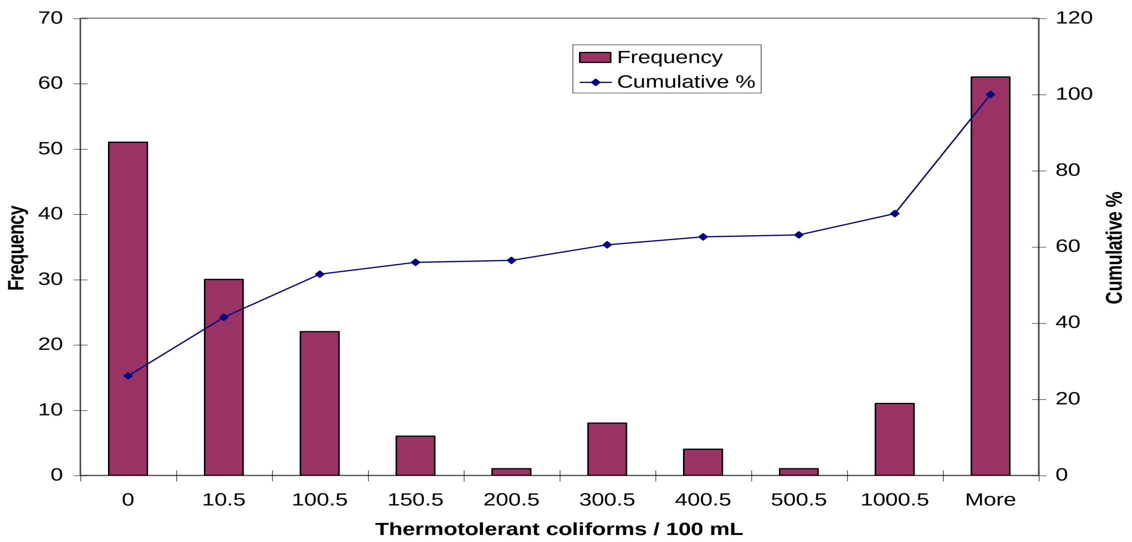

Figure 2: Frequency distribution of thermotolerant coliforms (combined data for all plants)

3.3 Relationships between Parameters

As shown in Figure 3, the correlation between BOD and SS for the combined data for all plants is poor. Likewise, there was no correlation between thermotolerant coliforms and parameters such total residual chlorine (TRC) or suspended solids as shown in Figure 4.

Table 5: Comparison of BOD and SS in effluent from on-site AWTS on a process basis

Process	No. of Samples	BOD, mg/L		Suspended Solids, mg/L	
		mean	S.D.	mean	S.D.
Activated Sludge	168	39	44	65	216
Extended aeration	16	29	21	159	281
Biofilter	16	33	44	24	16
Sand Filter	16	6	12	9	10

4 Discussion

4.1 Comparison of monitoring Programs A and B

The results of this part of the study indicate that grab samples taken at various times during the morning give a reasonable indication of the field performance of an AWTS. Local Government field monitoring programs that use grab sample procedures will give a good indication of field performance. Care must be taken at all times to ensure samples are collected in accordance with standard procedures.

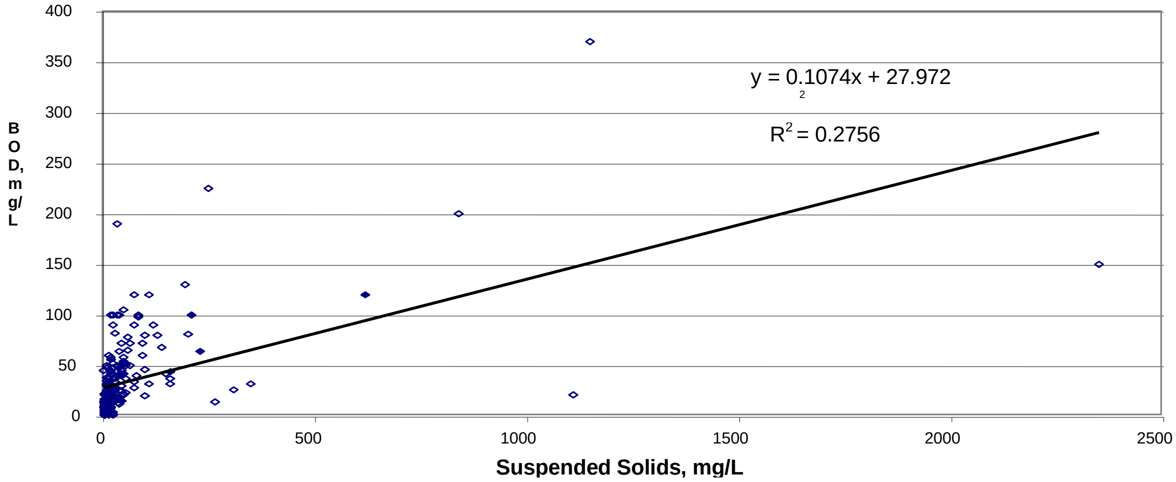

Figure 3: Relationship between BOD and SS for combined data for all plants

4.2 Compliance with Approval Criteria

It is clear that AWTS are not consistently meeting effluent quality standards set by the Department of Natural Resources. The results of this study reinforce the conclusions of Rogers, (1994). The best-performed system was the sand filter where 94% of the plants sampled complied with BOD and SS criteria. The performance of the sand filter was similar to that of the AWTS in meeting TC criteria, but it could be expected that disinfection would improve the effluent quality.

The poor performance of AWTS is probably due to several reasons. Analysis of the questionnaire data indicates that failure by homeowners to adequately maintain the plant is one significant reason. Many owners interviewed were not aware that the treatment process was biological and that excess use of strong household cleaners can upset the biological activity. Mechanical problems included failure to have aerators and pumps repaired.

The most common mechanical problem encountered was the failure of the chlorination system to provide dependable effluent disinfection. Common problems included tablets expanding and jamming in the dispenser thus preventing contact with the effluent and tablets being fully used before the quarterly servicing. The poor correlation between TC and TRC as shown in Figure 4 results from the above problems.

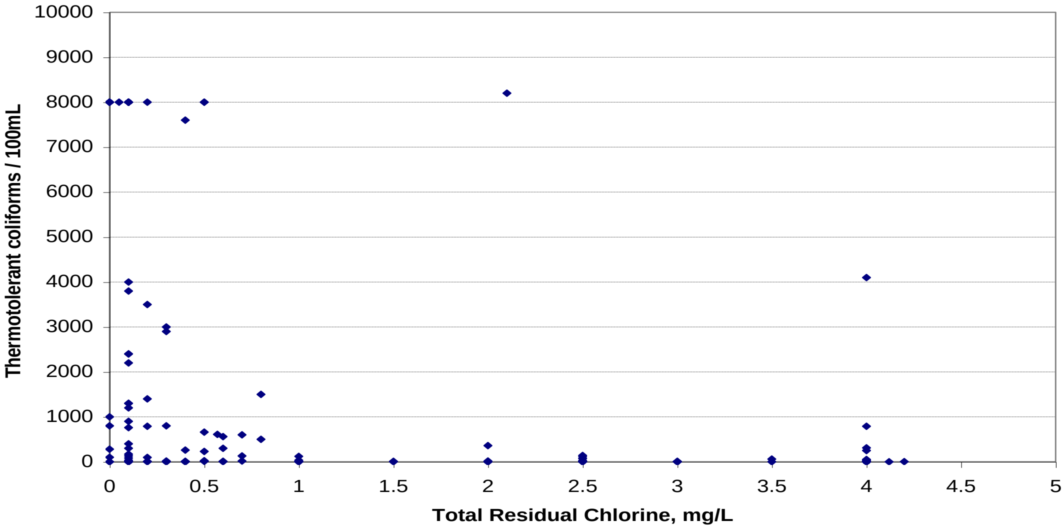

Figure 4 Relationship between TC and TRC (expanded scale) for combined data for all plants.

4.3 Solids capture

The basic design of the activated sludge, extended aeration and biofilter systems provides no barrier to solids carryover. Any excess carryover of solids from the primary settling tank will ultimately flow through the system to the final effluent. Khalife and Dharmappa (1996) made a similar observation.

It was noted during the inspections of the plants that waste sludge was not being returned to the primary settling tank. Waste sludge was observed floating in the secondary clarifier and the effluent pump well. The poor performance of many plants can be attributed to inadequate capture of solids. This is most likely due to inadequate maintenance rather than a design deficiency of the plant. If it were a design deficiency, then all plants evaluated would have failed to comply. Plants that were well maintained in general complied with effluent quality standards.

4.4 Disinfection

The results for TC are interesting in that, a high proportion of the plants sampled achieved a TC count of <10 cfu/100 mL. Effluent quality criteria for spray irrigation of effluent with uncontrolled access is TC <10 cfu/100 mL and turbidity of <2 NTU. This study seems to indicate the TC <10 cfu/100 mL is achievable. It is, however, unlikely that the requirement for turbidity of <2 NTU would be achievable without further treatment of the effluent.

Data from 161 one-tank disinfection systems and 25 two-tank systems was analysed to determine the effectiveness of the two systems. At all levels of disinfection the two-tank system outperformed the one-tank system. In the two-tank system 84% of plants achieved counts of less than 1000 cfu/100 mL while in the one-tank system only 68% of plants achieved less than 1000 cfu/100 mL.

A similar study in Western Australia (Devine, 1996) showed better disinfection performance with two-tank systems. It is a requirement in Western Australia that the disinfection compartment and effluent pump compartment are separate. This provides for a 20-minute detention time in the disinfection chamber. Manufacturers, as a means of improving effluent quality, should consider this design modification.

5. Conclusions

The conclusions derived from this study are as follows:

- the current local government field monitoring programs using grab sampling procedures provide a good indication of the performance of the plant;
- the failure of AWTS to consistently comply with effluent quality standards is due mainly to inadequate attention to maintenance of the plant;
- the chlorine disinfection system is inadequate. Results of the study show that there is no correlation between TC and SS, or residual chlorine;
- the AWTS appears to have problems with solids carryover from one compartment to the other, resulting in high levels of suspended solids in the effluent. This could be due to inadequate removal of solids from the primary settling tank and failure to return waste sludge from the secondary clarifier to the primary settling tank;
- sampling effluent from the clarifier to determine suspended solids concentration and effluent after disinfection to determine TC counts is considered to be an adequate measure of field performance of AWTS and sand filters;
- the sand filter is the best performed system with respect to BOD and SS removal. To improve the effluent quality in regard to thermotolerant coliforms, disinfection is recommended;
- the disinfection chamber and the effluent pump chamber in the AWTS should be separated; and
- provided the AWTS and sand filter are well maintained, quarterly services are carried out as required and chlorine tablets are correctly positioned in dispensers, satisfactory performance can be expected.

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