THE USE OF CLINOPTILOLITE IN A LOW COST AEROBIC SAND FILTER

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Abstract

As part of the NSW Septic Safe Program, funding was obtained to construct a low cost aerobic sand filter to treat domestic effluent. In the innovative sand filter design described in this paper, a layer of clinoptilolite (zeolite) filter media was incorporated to specifically remove the ammonium ion prior to nitrification. Nitrate in discharge waters is of concern with on-site effluent disposal as it can migrate offsite and lead to further water contamination.

The design described utilizes low cost materials and draws on existing knowledge relating to substrate technology from sub-surface constructed wetlands. Locally sourced sand meeting specific sand filter specifications was used in the design, while the clinoptilolite (which was also locally sourced) was used to remove peak ammonium concentrations by ion exchange processes. The investigations associated with the design of the low cost domestic effluent treatment system are described. As monitoring has only recently commenced, system performance cannot be evaluated in detail, however results are to be included in a report to the NSW Department of Local Government as part of the grant requirements. The monitoring work is being complemented by laboratory studies using columns to further evaluate the suitability of the filter media.

Keywords

aerobic, ammonium, clinoptilolite, domestic, nitrate, sand filter, wastewater, zeolite.

1 Introduction

Research undertaken overseas suggests that aerobic sand filters which are intermittently dosed significantly improve the quality of septic effluent, particularly in relation to the removal of particulate matter and pathogen numbers. Aerobic sand filters also result in conversion of nitrogen species to nitrate through the process of nitrification. Typical modern filters are commonly constructed for domestic wastewater treatment in many parts of the United States and New Zealand and some have been successfully developed in parts of Australia. Several Australian states even have specific guidelines for their design and construction, yet the technology has not been adopted in NSW and designs are not commonly available.

The NSW requirements for on-site sewage management for single households were substantially changed in 1998 in response to increasing concerns over the performance of existing systems and environmental and public health issues about on-site wastewater treatment and disposal. The new guidelines issued by the Department of Local Government (1998) acknowledge the important relationship between land capability assessment and the performance of soil based systems. They also identify a role for alternative treatment and disposal systems in achieving satisfactory outcomes where there are particular site and soil constraints to on-site effluent disposal.

This paper describes the construction of a wastewater treatment system on a residential property at Martinsville, NSW on the western side of Lake Macquarie. The soils at the site are thin and of low hydraulic conductivity and considered poor for on-site soil absorption. The alternative system described here was developed because a typical soil based system (under the new NSW regulations) was not practicable as a preliminary site and soil assessment by an on-site design consultant had recommended a total trench length almost 2 kms long. The current system was developed to demonstrate that alternative on-site systems can be designed to perform satisfactorily, be low cost and reliable with minimum maintenance requirements.

After investigating a wide range of options, a system was designed in which primary treatment is by septic tank and secondary treatment by an aerobic, intermittently dosed sand filter followed by a drip irrigation system. The 40 ha site on which the system was constructed is steeply sloping so it was decided that gravity flow between the components would be used in lieu of electrical pumps. A desire to dose the sand filter and drain-field led to the use of automatic dosing siphons that have no moving parts and require no long-term maintenance.

As part of the NSW Septic Safe Program, funding was obtained to construct and monitor the innovative system. Approval for the design was granted by Lake Macquarie City Council in 2000. In the sand filter design described, a layer of clinoptilolite filter media was incorporated to specifically remove the ammonium ion (prior to the nitrification) in the effluent. This filter media appears to offer specific advantages over typical filter sands in terms of additional treatment by ion exchange processes. The system commenced receiving domestic effluent in May 2001.

2 Zeolite Chemistry

Zeolite is the generic name given to hydrated aluminosilicate minerals of which clinoptilolite is one. During the formation of zeolites, some aluminium compounds replace silicon compounds on the surface of the zeolite. Each substitution creates a negative charge on the surface of the zeolite, which requires a cation (a positively charged ion such as ammonium, NH_4^+) to balance the charge. The greater the density of negative charges on the surface of the zeolite the greater its affinity for ammonium. Although there are many types of zeolites, clinoptilolite has received the largest attention due to its potential use as wastewater filter media (Nguyen and Tanner, 1998; Baykal and Guven, 1997; Bowlan and Mowatt, 2000; Sakadevan and Bavor, 1998).

Clinoptilolite removes contaminants from wastewater by a combination of adsorption and ion exchange. Adsorption involves the movement and accumulation of a substance, known as the adsorbate, onto the surface of another substance, known as the adsorbent. Ion exchange involves the selective uptake of certain ions, such as ammonium, by a particular substance, such as clinoptilolite, which occurs due to the charge and structural characteristics of both substances. When anion concentrations in a solution are low, ion exchange occurs, when they are high, adsorption takes place (Jorgenson et. al, 1976).

2.1 Zeolite Capacity

A recent study by Nguyen and Tanner (1998) revealed that, in laboratory column tests, clinoptilolite has a large capacity for removing ammonium from effluent. Their results indicated that the operating capacity, or the amount of ammonium taken up by the clinoptilolite, is dependent on the contact time (i.e. flow through rate) between the clinoptilolite and the effluent, with a greater contact time resulting in a higher operating capacity. Over 98% of the ammonium from the wastewaters (influent concentration 100 mg NH_4^+-N/L) was consistently removed by the clinoptilolite, even after receiving 40 bed volumes of wastewater (Nguyen & Tanner, 1998). Bolan and Mowatt (2000) found similar evidence that clinoptilolite had a large capacity for ammonium removal, with ammonium retention ranging from 1.63 kg to 13.05 kg NH_4^+-N per tonne of zeolite. They noted that the removal rates gradually decreased as the amount of effluent input increased.

2.2 Competing Ions

While clinoptilolite does have an ion exchange preference for ammonium, other cations within the wastewater, such as calcium (Ca^{2+}), sodium (Na^+), potassium (K^+), and magnesium (Mg^{2+}), compete with ammonium for exchange sites. This competition has been found to reduce the amount of ammonium removed by clinoptilolite. Nguyen and Tanner (1998) found large amounts of Na^+ present in the studied wastewater and concluded that this had reduced the amount of ammonium being taken up by the clinoptilolite. Bolan and Mowatt (2000) also found that Ca^{2+} and Na^+ provide strong competition with the ammonium, occupying between 10.3 – 65.5% of cation exchange sites. Between 6.8 – 52% of cation exchange sites were occupied by ammonium.

2.3 Regeneration

Clinoptilolite can be regenerated once it approaches its saturation capacity, allowing it to be used over a relatively long period of time. The ammonium is tightly held by the zeolite and is not released by flushing with distilled water (Nguyen & Tanner, 1998). For regeneration to occur, the ammonium-saturated clinoptilolite must be flushed with a chemical solution containing a high concentration of cations that will release the ammonium. Such solutions include sodium chloride, potassium chloride, and sodium hydroxide. These contain Na^+ and other cations and have been successfully used to regenerate the ammonium exchange sites, increasing the life span of the zeolites as a filter media (Nguyen & Tanner, 1998).

Baykal and Guven (1997) found that clinoptilolite lost only 10% of its total cation exchange capacity after being regenerated ten times. Bolan and Mowatt (2000) suggested even greater performance when regenerated with hydrochloric acid. Their research showed that even after 12 regenerations, the ammonium retention capacity of the clinoptilolite remained the same as that of the original samples. The chemical processes of ammonium removal by zeolite within sand filters will inevitably be accompanied by microbiological activity. This biological activity becomes increasingly advantageous to the ion exchange process as time passes (Baykal and Guven, 1997) due to the behaviour of certain bacteria which promote nitrification, followed by denitrification, which releases the nitrogen as an inert gas. This assists in renewing the capacity of the zeolite for further ammonium removal (Nguyen and Tanner, 1998). On the basis of this research and because of increasing concerns about the fate of nitrate in the environment, it was decided to incorporate a layer of zeolite in the aerobic sand filter constructed at Martinsville.

3 Method

3.1 System Description

The system constructed incorporated a septic tank, dosing siphons, an aerobic sand filter (with clinoptilolite layer), a collection well and sub-surface drip irrigation. A schematic diagram of the system is shown in Figure 1, while the sizing of the septic tank and the sand filter were based on the design criteria in Table 1.

A standard Everhard plastic baffled septic tank with a capacity of 3000 L was used, fitted with a GT150 effluent filter passing 1 mm maximum. An adjacent concrete tank, measuring 1.2 m high with a diameter of 0.9 m, was fitted with an automatic siphon that pressurizes the sand filter manifold with a head of 4.5 m. A float, proximity switch and digital counter were fitted to monitor siphon performance and hydraulic loads.

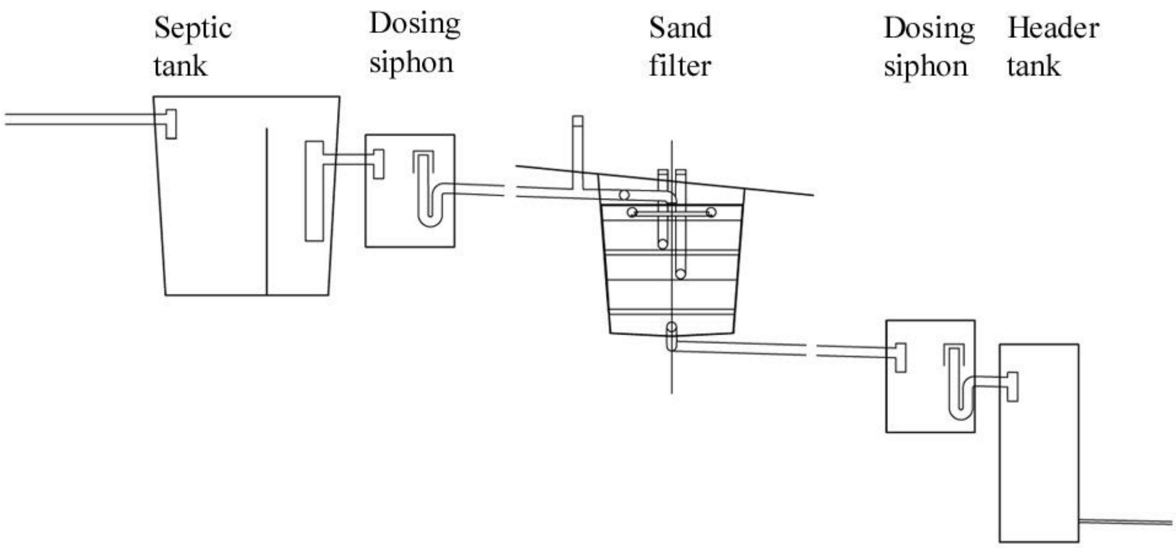


Figure 1: Schematic Section Through Wastewater Treatment System

Table 1: Design Criteria for Martinsville Domestic Wastewater System

Site Soils	representative permeability	0.024 m/day (clay)
	long term acceptance rate (LTAR)	8 mm/day
	pH	5.6
	Electrical conductivity (dS/m)	0.6
	Exchangeable Na^+ percentage	15%
	cation exchange capacity (cmol+/kg)	8.31
	phosphorus sorption capacity	1705 mg/kg
Water Supply	tank only; gutters fitted with first flush diverters	
	static head	165 kPa
	fixtures	No non-standard
	washing powder	minimized; environmentally friendly brand used
Hydraulic Load	Residence - 4person at 150 L/person/day	600 L/day
Sand Filter	design loading	50 L/m^2/day

The sand filter was arranged along the contours of the hillside site and measured 13.0 m long, 1.5 m wide and 1.3 m deep. A Nylex Aeon XOL flexible membrane liner was laid over sand blinding and up the sides of the excavation prior to installing the collection drain, gravel, sand, zeolite, distribution manifold, filter fabric and topsoil. A thin layer of pea gravel was used at the sand/gravel interfaces to prevent sand particle migration and to minimize biological mat accumulation. Sampling ports above and below the zeolite layer were also included. Figures 2 and 3 show the details of the sand filter, collection drain and distribution manifold.

An under-drain in the sand filter discharges into a second dosing tank also fitted with an automatic siphon. In turn the siphon discharges into a header tank that, allowing for pipe friction losses, pressurizes the sub-surface drain-field at a head in excess of 10 m. A final filter, passing one-tenth the orifice diameter of the drain-field emitters, was fitted in-line before the drain-field.

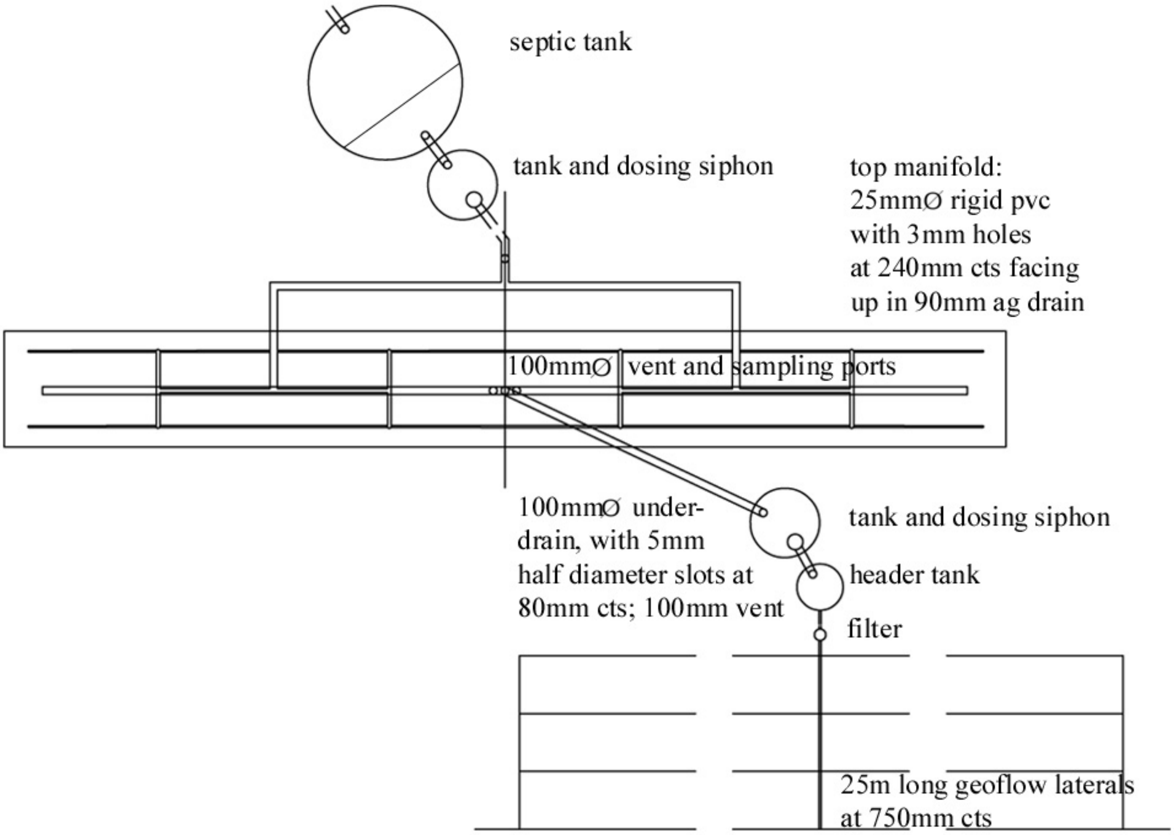


Figure 2 Schematic Plan of Wastewater Treatment System

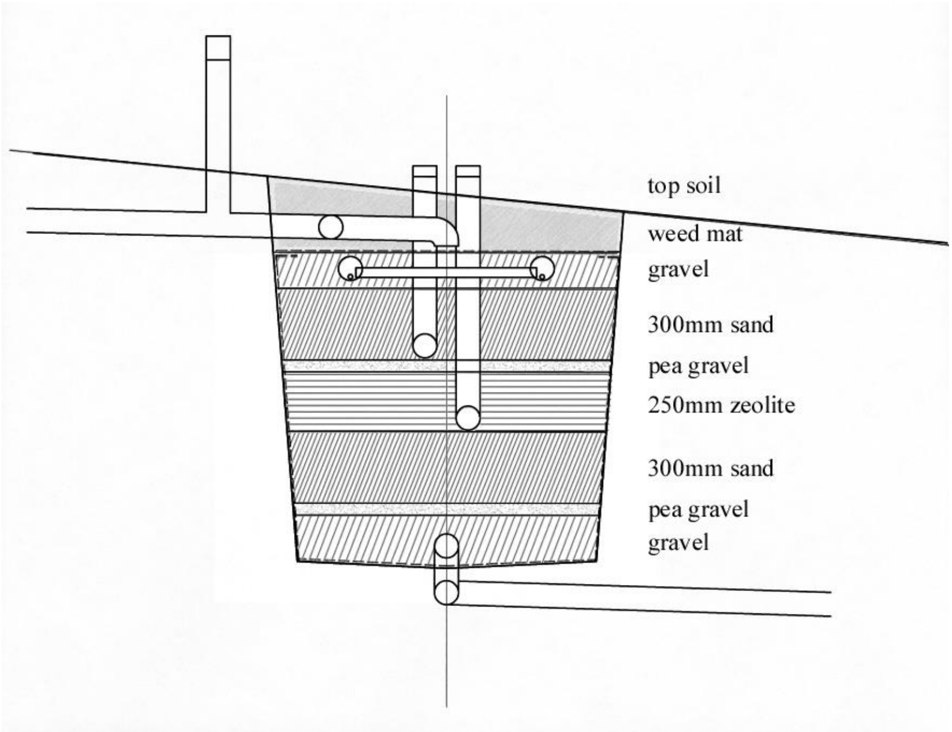
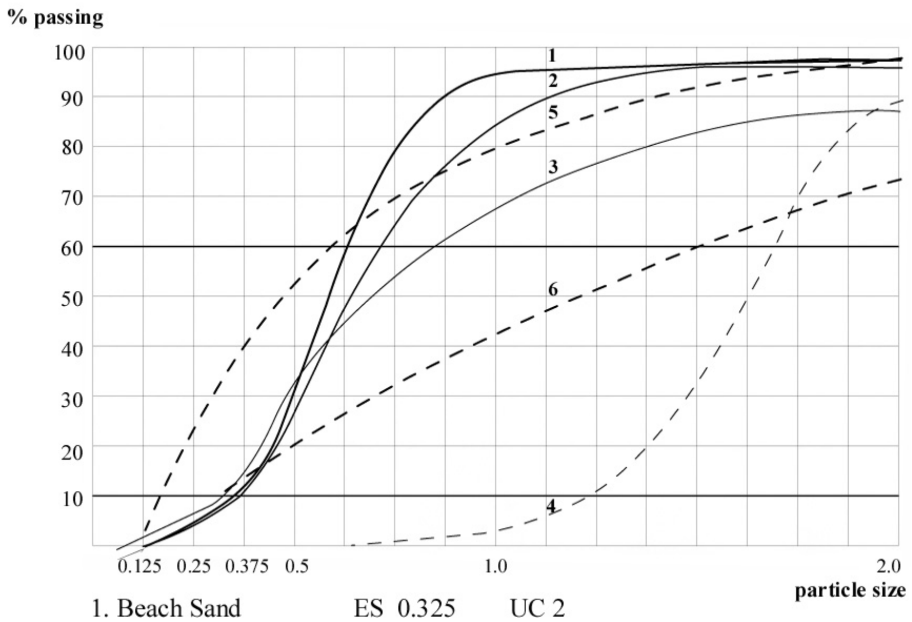


Figure 3 Section Through Aerobic Sand Filter Showing Clinoptilolite (Zeolite) Layer

A number of filter media were tested to determine effective size, uniformity coefficient, cost and local availability and reference was made to various design codes, for example, South Australian Health Commission (1995) and Washington State Department of Health (1999). Typical sieve analysis results for a number of the filter media are shown in Figure 4.

Filter media 1 (washed beach sand) was chosen as the principal component for the aerobic filter as it best met the specifications stipulated in the design codes (effective size of 0.325mm and a uniformity coefficient of 2). The washed beach sand was available locally. The total cost of the experimental system, including external house drainage, septic, dosing and header tanks, sand filter and drain-field, was approximately $10,000, excluding unpaid labour.



1. Beach Sand ES 0.325 UC 2
2. Crushed Sandstone ES 0.335 UC 2
3. River Sand ES 0.275 UC 3
4. Crushed Glass ES 1.2 UC 1.4

5,6. Washington State D of H recommended range

Figure 4 Filter Media Sieve Analysis

Monitoring of hydraulic flows after start-up indicated that the system was receiving a daily load of approximately 540 L/day, which is under design capacity (Table 1). The sand filter is therefore being intermittently loaded at approximately 27 L/m^2/day which is also under design capability. Monitoring of effluent quality before and after the sand filter is undertaken for pH, electrical conductivity, nutrients and a number of cations.

3.2 Column Experiments

Column experiments are being undertaken to evaluate the performance of clinoptilolite in removing ammonium from a simulated effluent. Four laboratory columns have been used in experiments at the University of Newcastle. They are approximately 90 cm in length, have an internal diameter of 44 mm with an internal surface area of 15.2 cm^2. A silicon tube is used to drain the leachate from a plug in the bottom of the column into a collection flask. The tube is clamped to control the outflow rate of the solution from the columns.

The four laboratory columns have been packed with clinoptilolite to a height of 250 mm (440 g) giving a packing density of approximately 1.18 g/cm^3. Three of the columns are replicates. The clinoptilolite is saturated with de-ionised water and then dosed with 1 L of simulated effluent containing 40 mg NH_4^+ -N, creating a falling head. The outflow rate is approximately 14 mL/min giving a hydraulic rate of 9.2 mm/min. Each of the runs has lasted 90 minutes. One of the columns was a control which had been set up as an identical column of clinoptilolite. It has been dosed with 1 L of de-ionised water rather than the ammonium solution. The samples at the completion of each run are collected and refrigerated at 4^{o}C until analysis is conducted. Analysis of cation concentration of the samples was determined using an ion-chromatograph.

4 Results

Monitoring of the field installation has only recently commenced. The initial results of the first sample only are shown in Table 2. It is proposed to continue monitoring the effluent quality both pre and post the aerobic sand filter at fortnightly intervals until the end of 2001.

The initial results of the laboratory column work are shown in Table 3. The results for the de-ionised water in the control are shown, while those for the clinoptilolite represent the mean concentration of the filtrate from the three replicate columns after applying 40 mg/L NH_4^+ -N. The results presented are for one run only. It is planned however to undertake multiple runs with the clinoptilolite columns and then replace the filter materials that are in place in the actual sand filter proportions as shown in Figure 3. Multiple runs using different concentrations are planned for later laboratory experiments.

Table 2 Effluent Quality Results – 23/05/01

Parameter (units mg/L)	Effluent Pre Filter	Effluent Post Filter
BOD_5	136	13
Total Kjeldahl Nitrogen	66.1	7.6
Total Oxidised Nitrogen	0.07	0.68
Total Phosphorus	7.9	1.4
Sodium	118.3	117.8
Ammonium	60.4	7.1
Potassium	23.5	11.6
Magnesium	4.4	13.3
Calcium	16.3	32.1

Table 3 Laboratory Column Results

Cation Concentrations (mg/L)	Control	Clinoptilolite Columns (N=3)
Sodium	2.73	37.7
Ammonium	0.073	0.51
Potassium	0.126	1.54
Magnesium	0.051	1.32
Calcium	0.178	4.15

5 Discussion

There are very few results at this stage of the experimental work. The limited data in Table 2 suggest that initially the sand filter appears capable of producing good quality effluent and this is promising. The post filter BOD_5 is low and most of the nitrogen from the septic tank is being retained within the sand filter. It is presumed that the clinoptilolite is retaining the ammonium ion as there has only been a minor increase in Total Oxidised Nitrogen through the sand filter. Of interest also is the fact that there has been some removal of Total Phosphorus, although the longer-term performance of the filter with respect to Nitrogen and Phosphorus will be of more interest. The results from the initial laboratory column work clearly show the affinity of clinoptilolite for the ammonium ion as the ammonium concentrations have been substantially reduced in the simulated effluent. Also of interest is the displacement of the sodium ion in preference for the added ammonium. Further work is underway and this will be reported in the scientific literature and in a final report as required under the Septic Safe Program grant.

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