‘Active’ filters for upgrading phosphorus removal from pond systems

A. Shilton*, S. Pratt*, A. Drizo**, B. Mahmood***, S. Banker*, L. Billings*, S. Glenny* and D. Luo*

*The Centre for Environmental Technology and Engineering, Institute of Technology and Engineering, Massey University, Private Bag 11222, Palmerston North, New Zealand
**Plant and Soils Science Department, University of Vermont, 105, Carrigan Drive, Burlington, VT 05405 Canada
***Unitec New Zealand, School of Built Environment, Engineering Discipline, Private Bag 92025, Auckland, New Zealand

Abstract
This paper investigates limestone and iron slag filters as an upgrade option for phosphorus removal from wastewater treatment ponds. A review of ‘active’ filter technology and the results from laboratory and field research using packed columns of the different media is presented. It is shown that both limestone and iron slag can remove phosphorus but highlights that different types of limestone give markedly different performance. Filter performance appears to be improved by increasing temperature and by the presence of algae, presumably because of its tendency to elevate pH. Performance is related to hydraulic retention time (HRT), but this relationship is not linear, particularly at low HRTs. Importantly for future research, the results from field-testing with pond effluent show significant differences compared to those obtained when using a synthetic feed in the laboratory. For the iron slag filter, higher performance was observed in the field (72% in field vs. 27% in laboratory, at a 12 hour-HRT), while the opposite was observed for the limestone (64% in laboratory vs. 18% in field, at a 12-hour HRT).

Keywords
Active filters; iron slag; limestone; nutrients; phosphorus; waste stabilisation ponds

Introduction
Water pollution from domestic and agricultural effluents has become a problem of great concern over recent times. Discharge of nutrients, particularly phosphorus (P), leads to eutrophication, algal blooms and general deterioration of receiving water quality (Harper, 1995). The need for new regulations to improve water quality has been recognised around the world and solutions for P removal from wastewater are currently being researched across a range of different wastewater treatment technologies (Ribaudo, 2003).

The use of active filters for P removal appears to offer a promising ‘appropriate technology’ for upgrading wastewater treatment systems for smaller communities and farms. The term ‘active’ is defined here to mean that in addition to physical straining, the filter media has chemical properties that support further treatment mechanisms. To date the research literature has predominantly reported on their use as an integral part of ‘wetland’ treatment systems, however, they potentially also offer an excellent method of upgrading ‘pond’ treatment systems which are typically poor at removing P.

Research in the constructed wetlands area has indicated that the principal P removal/retention mechanisms are adsorption and/or precipitation and complexation with Fe, Al or Ca rich substrate (Richardson, 1985; Steiner and Freeman, 1989; Richardson and Craft, 1993) and therefore the selection of the material is a crucial factor for filter design (Kadlec and Knight, 1996; Mann, 1997; Johansson, 1999; Drizo et al., 1999; Drizo et al., 2002). Ideally, the material needs to be cheap and locally available, but should also have a suitable combination of physical and chemical properties such as hydraulic conductivity, porosity, granulometry, specific surface area, Fe, Al or Ca content (Steiner...
and Freeman, 1989; Zhu et al., 1997; Kadlec and Knight, 1996; Mann, 1997; Drizo et al., 1999; Johansson, 1999; Liénard et al., 2001; Drizo et al., 2002). Over the past 10 years, various materials have been tested for their ability to retain P around the world (Drizo et al., 2002; Molle et al., 2003) including gravel, various sands, fly ash, light expanded clay aggregates, shale, bauxite, zeolite, half-burnt dolomite, laterite, wollastonite, marble, calcite, crushed concrete, and blast furnace slag. In Quebec, a thorough investigation was carried out comparing the performance of 57 locally available materials (Forget et al., 2001). Of those, electric arc furnace slag (EAF slag) had one of the highest P retention capacities and was selected for further examination in a full-scale system. Other authors also observed a high affinity of slag material for P at both low (5–10 mg/L, Yamada et al., 1986; Baker et al., 1998; Johansson, 1999; Crolla and Kinsley, 2002) and high (40–400 mg/L) loading rates (Drizo et al., 2002; Naylor et al., 2003; Lospied, 2003).

Filter materials rich in Fe, Al and Ca are known to have pH values that are usually either lower or higher than neutral and as such are detrimental for aquatic plant growth (Gersberg et al., 1986; Brix, 1994; Tanner, 2001). It is noted that this problem can be overcome by employing a multistage wetland design consisting of two or more flow cells, where some cells are planted (to enhance organic matter, suspended matter and nutrient removal via plant and microbial uptake) and others left unplanted, containing only the reactive material to enhance P retention (Brix, 1994; Drizo et al., 1999; Platzer, 2000; Liénard et al., 2001; Drizo et al., 2002). While these unplanted wetland sections may be very similar in appearance to what would be used for upgrading a pond, it must be remembered that the wetland and pond environments do have several different characteristics. Of particular relevance in ponds is the consumption of carbon dioxide by high algal concentrations that can result in significant elevation of pH. To date there has been very limited testing of the ‘active filters’ for pond applications.

The majority of the investigations so far have been conducted in laboratory batch experiments, while the longer-term studies in columns, pilot and full-scale systems have been limited (Mann, 1997; Baker et al., 1998; Johansson, 1999; Drizo et al., 1999, 2002; Gruneberg and Kern, 2001; Naylor et al., 2003; Molle et al., 2003).

This paper reports on a range of studies undertaken using two promising filter materials (iron slag, as discussed above, and limestone which is Ca rich and widely available throughout New Zealand). The primary objective of the paper is to present a range of preliminary findings to form a platform for further research into the application of active filters for upgrading ponds for P removal. Secondly the paper compares and contrasts performance from laboratory experiments feed on synthetic wastewater against those obtained under real field conditions so as to provide insight into methodology development for future research.

**Laboratory and field-scale experiments**

This section of the paper firstly reports on a series of shorter batch studies and then presents data obtained from columns run continuously for in excess of a year in the laboratory and for half a year in the field using both limestone and iron slag media.

**Batch experiments**

In these studies the work focused on limestone alone and was conducted in beakers batch fed with a synthetic P solution. A range of variables were assessed including media type and characteristics, temperature and the influence of algae to assess the sensitivity of these parameters.

Six kinds of limestone were obtained from different quarries throughout New Zealand. Density, porosity and calcium carbonate components were measured. The composition of
these varied significantly as did performance. As might be expected, higher performance appeared to be linked to higher porosity. The limestone selected for further use in this study was sourced locally from the Tararua region in the North Island of New Zealand. It had a bulk density of 1.34 g/cm³, an individual density of 2.68 g/cm³, a bulk porosity of 50% and a CaCO₃ component of 75%. It was noted to become slightly crumbly after soaking as opposed to other limestones, which had very flat and hard surfaces. It is perhaps important to note here that some previous researchers have simply reported the testing of ‘a limestone’. Clearly the characteristics of different limestones do vary widely as does their performance within an active filter. It is believed that this might explain the relatively poor results obtained in the limestone used by Strang and Wareham (2002).

A number of simple batch experiments were conducted to assess if temperature had any influence at temperatures ranging from 4°C to 35°C. It was found that temperature did have a significant effect with performance seen to vary by 60% over the temperature range tested. While more detailed analysis of the reaction kinetics is needed, this preliminary finding draws attention to the need to account for temperature in future experimentation. It also highlights that this technology may be particularly appropriate in warmer climates such as tropical regions where ponds are already extensively used.

A key point of difference in conducting a laboratory experiment using a synthetic P solution as compared with a field experiment using real pond effluent, is the high algae concentration contained within a pond. As mentioned previously, algal activity can elevate the pH in a pond. Because pH can have a significant impact on mechanisms such as precipitation this requires further consideration. To study this, batch testing was conducted using two solutions with and without the presence of algae and clearly indicated that the presence of the algae did correspond with enhanced phosphate removal efficiency.

While the batch experiments were effective for preliminary testing it was felt that the work should be continued using columns where a deeper media bed is used with a continuous through flow of wastewater. While variables such as temperature and P concentration can be held constant in the laboratory, the apparent influence of the algae pointed to the importance of also undertaking experimentation in the field.

Continuous flow column testing – laboratory
In these experiments both the Tararua limestone and an iron slag (of similar size) sourced from the electric arc furnace at the BHP steel mill in Waiuku, New Zealand were tested. This iron slag media had a bulk density of 1.37 g/cm³, an individual density of 3.04 g/cm³, and a bulk porosity of 45%. Columns of 150 mm diameter were constructed and filled to a depth of approximately 1 m with the media. Pumps then delivered a continuous solution containing 10 mg/l of P from a holding tank up through the flooded column. The column testing was undertaken in a constant temperature laboratory at 25°C.

A column of the limestone was run for approximately 10,000 hours at a hydraulic retention time (HRT) of 12 hours. One slag column was tested at HRTs of 3 and 48 hours and another slag column was tested at HRTs of 12 and 72 hours. The total testing time for the slag columns was approximately 5000 hours at each of the two different HRTs.

At the comparable HRT of 12 hours it was found that the limestone filter performed far better than the iron slag filter giving an average P removal of 64% compared to 27% for the slag. It is noted that a trend for both filter types was for a start-up effect where the P removal efficiencies were initially high, then dropped before settling to a more steady-state performance. This phenomenon was also observed in a similar experiment in Canada (Drizo et al., 2002).
Understanding the relationship between filter performance and hydraulic residence time is important for filter sizing. The effect of HRT on the performance of the iron slag filters for HRTs of 3, 12, 48 and 96 hrs is shown in Figure 1. It can be seen that the performance of the slag filter was shown to increase with an increase in HRT, presumably because the contact time for adsorption, precipitation and complexation was enhanced. It is noted that the relationship is not linear, particularly for low HRTs.

Continuous column testing – in the field
The field experiment was conducted at a local waste stabilisation pond system (Ashhurst, NZ) on the final effluent from a two-stage facultative pond system. Two columns (identical to those used in the laboratory experiments) were established, again using the Tararua limestone and iron slag, and continuously fed with the final pond effluent. Both were operated at a 12-hour HRT. These experiments were conducted over a period of approximately 4400 hours.

The results were surprising. In a reversal from the laboratory work, the efficiency of the slag filter was markedly improved achieving an average performance of 72% (up from 27% in the laboratory).

Conversely, the performance of the limestone filter now decreased to an average of only 18% significantly down from the value of 64% obtained under laboratory conditions. Interestingly, this behaviour of the limestone is similar to that reported by Arias et al., (2003) who also observed that Ca rich filter material (calcite) had higher performance in laboratory experimentation as compared to the field.

Continuous column testing – comparison of laboratory and field results
Based on the findings of the batch experiments, the presence of the algae in the field pond would have been expected to improve the performance in the field experiment, as was the case for the iron slag. Alternatively because the temperatures at the field were certainly much lower than those of the constant temperature room at the laboratory, this would have been expected to have the effect of lowering the performance in the field, as was the case for the limestone.

While this result was unexpected it is certainly interesting and indicates that:
1. The predominant mechanisms acting to remove the P within the filter may be different between these two materials
2. The use of laboratory experiments to research active filters may not be entirely representative of the full-scale systems they are meant to represent.

Figure 1 Iron slag filter performance in the laboratory as a function of hydraulic residence time (HRT)
Conclusions

While there is considerably more literature on active P removal filters in the wetlands field, it is noted that differences between the wetland and pond environments require consideration.

The performance of limestone filters varies markedly with the type of limestone used. While the Tararua limestone was reasonably effective in the laboratory, it performed poorly in the field.

Filter performance appears to improve with increasing temperature. The consequence of this being that active filters may be more effective in warmer climates.

Algae activity in ponds appears to improve filter performance, potentially due to the consequential elevation of pH that, in turn, improves precipitation reactions.

Increasing HRT also improves removal efficiency, but this relationship is non-linear with the degree of improvement gained reducing with respect to time.

Iron slag proved to be an effective media in field conditions achieving an average P removal of over 70% at a 12-hour HRT.

Laboratory based research using synthetic wastewater is not effective at representing full-scale systems.

Considering the expensive alternative of chemical dosing, we must investigate more ‘appropriate’ technologies for upgrading P removal to ensure that pond technology remains a viable treatment option in coming decades. The work presented here can only be considered a start, but given the good results produced by the iron slag filters, it seems clear that with further research this technology offers a very promising solution for upgrading ponds to achieve improved P removal in the future.

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References


