Reed bed dewatering of agricultural sludges and slurries


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Abstract In trials at Rugeley, UK, reed beds were used for dewatering agricultural sludges and slurries. Three beds, each of 3.5m², were employed, two planted with Phragmites australis, the third left unplanted as control. The sludge contained partly oxidised solids from a Biological Aerated Filter (BAF) treating weak pig slurry. It was supplemented with untreated settled pig slurry. Following reed establishment planted Bed A was fed at a constant similar rate to the unplanted Control Bed C. The second planted Bed B was fed at higher rates alternating with rest periods. On this bed the aeration pipes were blocked off. The trials were run for 16 months, which included two summer periods. The results showed that the planted Bed A had definitely better dewatering ability than the unplanted one fed at a similar rate. During the summer months Bed B could be fed at over twice the rate used for the constant input beds. The percolate from the control bed was more highly oxidised than from the planted beds, probably due to a longer holdup time in the absence of reeds. On Bed B the reed quality deteriorated during the second year, after use of untreated slurry as feed.

Keywords Percolate quality; primary sludge treatment; reed beds; sludge dewatering; sludge drying; sludge loadings

Introduction

Although far less numerous than reed beds for wastewater treatment, vertical flow reed beds have been employed for dewatering sludges for over 30 years. Such beds, in which Common Reed, Phragmites australis, is planted in soil, sand or gravel, appear to offer both economic and environmental advantages over alternative methods of sludge dewatering. They are far more effective than sand bed drying which is now almost extinct; they do not require chemical flocculants and centrifuges or belt presses. For small rural sewage treatment works (STW), particularly those employing only intermittent supervision, such reed beds can obviate the need for road tankers to convey the sludge to larger works for treatment.

In such dewatering operations sludge is fed onto the vertical flow reed bed periodically. It becomes dewatered by percolation through the preceding sludge layers and the matrix, by evapotranspiration through the reed roots, stems and leaves, and by evaporation from the sludge surface. Movement of the stems in the wind keeps open the drainage passages down through the sludge layer. With slow percolation of oxygen into the sludge layer, both via the reed plants and their root zone, and by diffusion through the air-sludge interface, the sludge gradually becomes oxidised/mineralised with a reduction in volatile solids and an increase in % ash or fixed solids. With gradual loss of moisture the % Total Solids (TS) of the dewatering sludge can build up towards 50% (De Maesener, 1996).

Most of the full-scale experience on reed bed dewatering comes from Denmark, much arising from the work of Nielsen (1990,1994). In Denmark about 25 such units have been installed on STW with another 35 under consideration. They serve communities from 5,000 to over 100,000 inhabitants. Reed bed dewatering appears to be economically competitive to the use of flocculants/centrifuges and requires far less supervision and maintenance. In Danish practice there is usually no primary settlement of sludge; all the sewage goes into an
oxidation ditch. Thus the sludge fed to the multiple reed beds is well oxidised, usually con-
tains less than 1% solids, spreads easily and permits some 10 years operation before bed
emptying.

In France, Lienard and co-workers at CEMAGREF have done extensive work at pilot
plant scale (Lienard et al., 1990, 1994). However, there does not appear to have been any
major adoption of reed bed dewatering on a large scale in that country. In the USA, Kim
(1993, 1997) has reported on 24 of the 50 small municipal STW in which reed beds have
been used for sludge dewatering.

In the UK there now appear to be major opportunities for use of the technique (Cooper
and Willoughby, 1999). Since 1998 the disposal at sea of sewage sludge has been banned.
There is now a Landfill Tax of £11 per tonne for the disposal of waste to landfills; this tax is
being increased by £1 per tonne annually for the next few years as the UK Government
intends to greatly restrict the use of landfills for waste disposal.

So far in the UK few full size sludge drying reed beds are in operation. West of Scotland
Water built a unit at Ballygrant on the Isle of Islay in 1995 and a second at Kiells in 1998;
these take sludge from oxidation ditches. Both units were designed by Cooper at WRc
(Cooper et al., 1996). Severn Trent Water has been carrying out sludge dewatering trials for
several years at small STW using both primary and mixed sludges. In 1999 the Wildfowl
and Wetlands Trust commissioned a unit at their bird sanctuary at Slimbridge. On a smaller
scale, Burka installed a bed for a community at Oaklands Park in Gloucestershire in 1989
while Moodie constructed one for the National Trust at Dudmaston, Shropshire in 1992
(Nuttall et al., 1997).

For several years the University of Birmingham and A.R.M. Ltd. have studied the reed
bed dewatering of sludges and slurries from agricultural sources (Edwards, 2000). The
trials are the subject of this paper.

Methods

A pilot scale reed bed system was built at A.R.M. Ltd., Rugeley, Staffordshire, UK in
December 1995 to dewater the settled humus sludge produced by a Biological Aerated
Filter (BAF) unit when treating the wastewater from pig pens. The humus is the organic
slime material which sloughs off from the plastic packings of the BAF reactors when
operating. The reed bed system consists of a sludge holding tank and three identical vertical
flow beds (Edwards, 2000). Two of the beds, A and B, were planted with Phragmites
australis; the third bed, C, was left unplanted as a control.

Bed construction

The system was built above ground in blockwork. Each of the three beds is 2.6 m long by
1.27 m wide and 1.0 m deep comprising 500 mm depth of matrix and 500 mm of freeboard.

The matrix is of graded gravel as follows:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top layer</td>
<td>100 mm</td>
<td>1–2 mm rounded sea gravel</td>
</tr>
<tr>
<td>Then</td>
<td>150 mm</td>
<td>5–10 mm pea gravel</td>
</tr>
<tr>
<td>Next</td>
<td>100 mm</td>
<td>20–30 mm gravel</td>
</tr>
<tr>
<td>Bottom layer</td>
<td>150 mm</td>
<td>30–60 mm stones</td>
</tr>
</tbody>
</table>

For the top layer rounded sea gravel was employed in preference to sharp sand which in the
past has led to major blockage problems with reed beds at Rugeley treating wastewater.

The sludge in the holding tank was stirred by hand with a paddle and then pumped into a
graded vessel to ensure the required volume of the load; it was then hosed under hand
control onto the bed spreading it evenly. With the first loads onto the beds it was difficult to
form a sludge layer; it would have been better to blind the sea gravel surface with a thin layer of compost to form the initial filtration layer of solids.

After passing down through the bed matrix, in which some degree of treatment takes place, the percolate is discharged via a swivelling elbow to a 110 mm diameter pipe. This allows the water level in the bed to be controlled, being raised during the start-up period to aid reed establishment and during very hot weather to prevent the reeds becoming stressed due to lack of water in the root zone. During normal operation the bed is allowed to drain freely to help air diffusion back into the matrix. On discharge the percolate can be pumped to a nearby wastewater reed bed system for further treatment. Two aeration pipes were built into the matrix across the bed width; lower down a single aeration pipe runs the length of the bed. These are in 100 mm perforated plastic pipe. On Bed B the vertical risers from these pipes were capped in order to examine the effect of restricting matrix aeration on bed performance.

Two of the beds, A and B, were planted with *Phragmites australis* in January 1996 at a density of 4 plants/m². After planting, the beds were flooded to the surface with a weak solution of pig manure slurry diluted with tap water. This provided the reeds with nutrients for growth and adequate water to prevent stress in hot weather. During the summer months of 1996 further applications of solution were made. Within the first year the reeds spread to provide virtually a complete surface coverage. Bed C was left unplanted.

**Characterisation of the sludges**

Soon after operations started on the dewatering beds it became clear that the volume of humus sludge produced by the BAF system was much lower than expected and was insufficient to maintain an adequate loading regime on the beds. It became necessary to augment the volume of sludge available for dewatering.

The feed for the BAF unit was prepared from pig manure slurry sedimented in a storage tank, the supernatant being drawn off and diluted with tap water to the required level of Biochemical Oxygen Demand (BOD). The raw settled solids from the bottom of this tank were therefore blended with the treated humus sludge from the BAF unit to provide enough feed material for dewatering; the combination of these two sludges started on 30/7/97. Then in October 1997 the BAF unit was shut down; thereafter only the raw manure slurry solids were available for the dewatering trials. The various sludge feeds are shown in Table 1.

Over the trials period a series of samples were taken of these sludges and analysed for a range of characteristics, shown in Table 2. The analytical methods used are given in Edwards (2000).

**Dewatering trials**

*Commissioning phase*. Although Nielsen (1994) recommends a commissioning phase of 3 years to allow the reeds to grow and the roots and rhizomes to become well established in the bed matrix, this was clearly impossible with a PhD project. In the UK, Cooper *et al.* (1996) suggest a 1 year reed establishment phase; this was more appropriate to the present trials. During this commissioning year the two planted beds, A and B, were lightly loaded with two applications of BAF sludge to assess the potential dewatering capacity of the beds.
system and to help set up a sludge loading plan for the project. On 5/9/96 a volume of 87.5 l of sludge was measured out and applied to Bed A, providing a layer 25 mm thick. Then on 26/9/96 a sample of the partially dewatered sludge layer was taken from Bed A and analysed for TS content. A further 25 mm layer of sludge feed was added to Bed A and a 50 mm layer applied to Bed B. On the 10/10/96 samples of both dewatered layers were taken and analysed for TS. In addition to obtaining operating experience with the dewatering beds, these sludge applications greatly benefitted the reed growth. However, the total sludge loading used in this period was only about 3 kg dry solids (ds)/m².y, much less than the 18.3 kg ds/m².y recommended by Lienard et al. (1995).

Main trials. The loading of sludge for the main trials started in May 1997 and finished in September 1998, giving 70 weeks of investigations which included two summer periods. As shown in Table 1, during the initial part of this period only BAF Humus Sludge was used, then a combination of BAF Humus Sludge and Raw Slurry Solids; finally only Raw Slurry Solids were employed.

During the trial period Bed A and Control Bed C were loaded, as far as possible, with similar quantities of feed to compare the capabilities of a planted and an unplanted bed. Over this time of 70 weeks a total of 2,200 mm of sludge were added in 34 applications to Bed A, an average of 31 mm per week which, with the sludge averaging 4.07 w/w% TS, gave a loading of 67.7 kg ds/m².y. This figure is close to the loading of 60 kg ds/m².y suggested by Cooper et al. (1996) for an established bed. In practice, however, virtually no sludge was applied during the winter period from late October 1997 to mid March 1998. As a result the 60 mm layers added during most weeks of the active season corresponded to a loading nearer 120 kg ds/m².y, right at the top of the range suggested.

Bed B was tested under different loading rates. Although the total sludge added over the period was only slightly more than on the other two beds, the 26 applications included layers of 120, 180 or 240 mm depth; these heavy applications were then followed by several weeks of rest. Although Bed B was constructed with aeration pipes through the matrix, these were blocked off in the trials.

Quality of percolates. An investigation was made of the quality of the percolates leaving the three beds between 5/3/98 and 18/8/98 to assess the effect of the presence of reeds on Beds A and B, the blockage of the aeration pipes on Bed B, and the heavier but less frequent sludge applications to Bed B. The samples were analysed for COD, BOD, SS, DS, pH, NH₄-N and o-PO₄.

Results and discussion
Characterisation of the sludges
As shown in Table 1, three different blends of settled humus sludge from the BAF unit and raw pig slurry solids were used to make up the feed to the dewatering beds over the 70 weeks of the investigation. Samples of the feed were taken frequently and analysed for a range of characteristics. The detailed results are given in Edwards (2000) but the mean results are shown in Table 2.

Using wastewater/sludge flows from a commercial farm operation it was only to be expected that the TS contents of the three feed sludges were highly variable, ranging between 1.18 and 9.20% w/w with a mean of 4.07. This led to the high standard deviations shown in Table 2 for many characteristics.

Commissioning phase
On 5/9/96, eight months after the reeds were planted, a 25 mm deep layer of sludge was
added to Bed A. Then on 26/9/96 a sample of the sludge layer was taken and the TS content of the dewatered sludge found to be 38.9%, representing a high degree of water removal. The same day a further 25 mm layer was added to Bed A and 50 mm to Bed B. Then on 10/10/96 samples of the sludge layers were taken from both beds. That from Bed A had a TS of 21.4%, that from Bed B had 21.9%.

Dewatering trials

Sludge loadings and final residues. Following the preliminary loadings, the main sludge loading of the beds commenced on 16/5/97 and concluded with the final addition on 17/9/98, a total of 70 weeks. Over this period Bed A and Control Bed C were loaded at virtually the same rates in increments of 60 mm layers in most weeks, apart from the winter period from late October 1997 to mid March 1998 when few additions were made. Bed B was used to test the effect of much larger increments with some 120, 180 and 240 mm layers. Following the final sludge loadings the beds were left until 25/2/99 when the final residual sludge heights were recorded. The overall sludge loadings and final residue heights are given in Table 3.

The heights of the final residues indicate that planted Bed A achieved a dewatering ability of 84.3%, whereas that of unplanted Bed C was 81.1%. Planted Bed B, fed with larger and less frequent dosings, achieved a reduction of 86.3%. The final residue height of about 350 mm for the planted beds resulted from 70 weeks of sludge loading, an annual increase of 260 mm. This is much greater than the value of 150 mm/y stated by Nielsen (1994) for beds after 10 years of operation. A far more detailed analysis of the present sludge loadings and residue heights is given by Edwards (2000); in this the experimental period is divided into five seasons – Summer, Autumn and Winter 1997, Spring and Summer 1998. This analysis shows the major reduction in loading necessary during the winter months and gives a good comparison between the results in the two Summer periods.

A major finding was that during summer 1998 the reed growth was not as good as in summer 1997, with less bed coverage and lower stem heights. This was probably because in the second season of active growth some newly emerging shoots were overwhelmed by the raw inlet sludge when the loadings were increased in the spring following low loadings over winter. This contrasts with Danish experience when handling aerobic sludges from oxidation ditches and anaerobic sludges following digestion. Obviously the challenge for the UK is to find suitable sludge loadings and operating techniques for dewatering raw primary sludges, or their mixtures with secondary ones, without affecting reed growth.
Analyses of residual sludge layers. The final sludge loads were applied to the beds on 17/9/98. Then six weeks later, on 28/10/98, the height of the residual sludge layer was measured and samples of the dewatered sludge taken and analysed for TS and VS. The height measurements and analyses were repeated every 6–8 weeks for a period of 5 months until 25/2/99. The final heights are given in Table 3.

The sludge samples taken were core samples of the total depth of residue on each bed. The cores were then divided into 100mm deep segments to allow an estimation of the sludge characteristics at different depths in the residue and a mean overall value of the TS to be calculated. Table 4 shows the results from the final sludge cores taken on 25/2/99, 161 days after the final sludge was applied.

Table 4 shows that the mean values of TS were higher on the planted beds, A and B, than on the unplanted Control Bed C, indicating that the reeds aided the dewatering process. The TS value on Bed B, where the aeration pipes were blocked off, was slightly higher than on Bed A, suggesting that matrix aeration does not help dewatering. Analyses of the four horizontal slices of each core showed that generally the TS were highest at the top and bottom of the core, lowest in the middle section.

The VS were generally higher at the top of each core but the mean overall value showed little difference between the three beds. The mean values of VS, approximately 52.5% for the three beds, is a major decrease from the VS value in the fresh sludge, 74.2% in Table 2, showing that significant oxidation/mineralisation had occurred.

Examination of the cores of the final residual sludge layers showed that on both planted Beds A and B two distinct zones had formed – an anaerobic black upper layer, 300–350 mm deep, and a more oxidised lower brown layer, 50–100 mm deep. The two layers were also present on the unplanted Control Bed C but the oxidised lower layer was only 5–10 mm deep. These results indicate that, among other factors, the oxygen provided by the reeds aids the stabilisation of the sludge.

Quality of percolates. In Table 5 are summarised the mean results of the analyses of the percolates leaving the three dewatering beds between 5/3/98 and 18/8/98.

Lienard et al. (1995) and Hofmann (1990), using weak sewage sludges, have shown that planted beds give better percolates, with lower values of COD, BOD, SS and NH₄-N. In the present trials, using much stronger agricultural sludges, the planted Bed A has a lower

<table>
<thead>
<tr>
<th>Sludge added, m³</th>
<th>Bed A</th>
<th>Bed B</th>
<th>Bed C</th>
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</thead>
<tbody>
<tr>
<td>Height of added sludge, mm</td>
<td>2200</td>
<td>2561</td>
<td>2081</td>
</tr>
<tr>
<td>Final residue on bed, m³</td>
<td>1.14</td>
<td>1.16</td>
<td>1.30</td>
</tr>
<tr>
<td>Height of final residue, mm</td>
<td>345</td>
<td>392</td>
<td>395</td>
</tr>
<tr>
<td>Reduction in height, %</td>
<td>84.3</td>
<td>86.3</td>
<td>81.1</td>
</tr>
</tbody>
</table>

Table 3  Overall sludge loadings and final residue heights, period May 1997 to February 1999

<table>
<thead>
<tr>
<th>Column depth mm</th>
<th>Bed A</th>
<th>Bed B</th>
<th>Bed C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–100</td>
<td>20.77</td>
<td>54.38</td>
<td>23.46</td>
</tr>
<tr>
<td>100–200</td>
<td>20.82</td>
<td>53.41</td>
<td>19.37</td>
</tr>
<tr>
<td>200–300</td>
<td>18.24</td>
<td>51.21</td>
<td>21.09</td>
</tr>
<tr>
<td>300–400</td>
<td>22.09</td>
<td>50.99</td>
<td>22.11</td>
</tr>
<tr>
<td>Mean value</td>
<td>20.48</td>
<td>52.50</td>
<td>21.51</td>
</tr>
</tbody>
</table>

Table 4  Analysis of final sludge residue cores taken on 25/2/99
value for COD than the similarly loaded but unplanted Control Bed C but higher values for BOD, SS and TDS and comparable levels of NH₄-N and o-PO₄. Bed B with its higher sludge loadings had a definitely stronger percolate than did the other two beds. A possible cause of the better performance by the unplanted Bed C is that in the absence of reeds to keep open the passageways through the sludge layer, the hydraulic conductivity through the latter was much lower; this led to a longer holdup time in both the sludge and the gravel matrix, giving longer for percolate treatment.

Conclusions

1. The planted reed beds showed a definite improvement over the unplanted one in terms of higher % Total Solids and greater % Reduction in the height of the residual layer of sludge. They also showed a much deeper oxidised lower sludge layer. However, there was little difference in % Volatile Solids.

2. High loadings of raw sludges/slurries in the Spring can seriously damage the newly emerging shoots of reed plants.

3. In the Summer it is possible to dose dewatering reed beds with much higher loadings than 60 kg dry solids/m²-y, often regarded as the maximum year round average in the UK.

4. In terms of the BOD, Suspended Solids and Dissolved Solids of the percolates, the planted beds performed worse than the unplanted one. This was possibly due to their higher hydraulic conductivity, giving less time for treatment in the sludge layer and the matrix.

Acknowledgements

The authors gratefully acknowledge the financial support and help given to the project by the BOC Foundation for the Environment, the Engineering and Physical Sciences Research Council and A.R.M. Ltd.

References


Table 5 Characteristics of percolates from sludge dewatering beds, 5/3/98 to 18/8/98

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>COD mg/l</td>
<td>1822</td>
<td>607</td>
<td>2220</td>
<td>1085</td>
<td>1962</td>
<td>1018</td>
</tr>
<tr>
<td>BOD mg/l</td>
<td>1123</td>
<td>588</td>
<td>1468</td>
<td>746</td>
<td>935</td>
<td>539</td>
</tr>
<tr>
<td>SS mg/l</td>
<td>809</td>
<td>419</td>
<td>917</td>
<td>455</td>
<td>770</td>
<td>429</td>
</tr>
<tr>
<td>DS mg/l</td>
<td>3674</td>
<td>624</td>
<td>4055</td>
<td>655</td>
<td>3290</td>
<td>601</td>
</tr>
<tr>
<td>pH</td>
<td>8.02</td>
<td>0.22</td>
<td>7.65</td>
<td>0.17</td>
<td>8.17</td>
<td>0.24</td>
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<tr>
<td>NH₄-N</td>
<td>471</td>
<td>226</td>
<td>589</td>
<td>221</td>
<td>474</td>
<td>177</td>
</tr>
<tr>
<td>o-PO₄</td>
<td>569</td>
<td>154</td>
<td>590</td>
<td>57</td>
<td>583</td>
<td>145</td>
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