The search for green, low-energy technologies to treat effluents have brought a revival in the use of engineered reed bed systems to treat effluents. Professor Joe Biddlestone and David Cooper have been heavily involved in the promotion and installation of constructed wetlands in the UK. Here they write about this natural method of disposal and treatment of dirty water.

The use of wetlands to treat effluent is not a new idea. The Chinese and Egyptians used natural wetlands to clean up liquid effluent thousands of years ago. Constructing wetlands however is relatively new with Australia creating the first recorded construction at the beginning of the last century. Research in the USA into the field did not begin until the 1970s and the UK has only been using reed beds since 1986. Now, however, it is recognised that constructed wetlands are both an economic and a natural method of treating liquid effluent.

CONSTRUCTING WETLANDS

Today, more than 1,500 constructed wetland treatment systems operate in the UK. Put simply, the engineered reed bed is an artificially created wetland that contains specially selected species of reeds, or sometimes rushes, planted in gravel or soil. This set up provides a home for huge colonies of microorganisms that break down any organic pollutants from an inflow of dirty water, leaving the outflow cleaner. These engineered systems are designed to optimise the actions of the natural purification process and can treat many wastewaters from domestic sewage and grey water to industrial effluents and road run-off. Reed beds are typically built at or below ground level, only occasionally above ground, and usually filled with soil or gravel.

Aquatic or marsh plants (emergent macrophytes) are then planted in this medium with the Common Reed, Phragmites australis, being the most widely utilised, although alternatives such as the Great Reedmace, Typha latifolia, are also used. The type of vegetation is key to such systems. Indeed, studies indicate that microbial populations within gravels containing Phragmites and Typha are far greater than those existing in gravel alone.

RHIZOSPHERE

So why can these microorganisms – mainly bacteria – commute so successfully in reed beds? The answer lies largely in the root systems of the aquatic plants. These root systems consist of rhizomes, which contain thick hollow air passages from which finer roots hang down. The rhizomes grow horizontally and vertically, helping to keep pathways open for the passage of water through the reed bed.

The plants absorb a small amount of oxygen from the air and release it through their roots. Oxygen is transmitted to the root zone, also known as the rhizosphere, through the leaves and stems of the plants, and is then exuded from the finer roots. This process helps the rhizosphere initiate and support large populations of aerobic microorganisms, which thrive in oxygen-rich environments. Meanwhile, populations of anaerobic microorganisms congregate away from the root zones, as they do not rely on oxygen for growth.

Such a set up means that, as wastewater passes through the rhizosphere, it encounters alternate aerobic and anaerobic microbial populations. These convert carbonaceous, and to a lesser extent nitorgenous and phosphatic contaminants, into less polluting materials.

HELPING THE PROCESS

While the natural activity of plants and microorganisms is crucial in wastewater treatment, engineering knowledge is essential to ensure a fully functioning reed bed is properly built and continues to operate effectively during its lifetime. Initial considerations include preparing the excavation and then sealing it to prevent leakages. Getting the right bed geometry is also critical to achieving the required hydraulic flows when using matrix materials with different hydraulic conductivities. The effluent level and flow rate through the bed also need to be carefully controlled to ensure that the wastewater receives the necessary treatment. A sufficient level of ‘liquid hold-up’ or retention is critical to the effectiveness of a system.
BUILDING A REED BED

**HORIZONTAL FLOW BEDS**
Several types of reed bed exist, categorised according to hydraulic flow, such as horizontal flow, vertical flow, surface flow, and hybrid beds. Horizontal flow beds are the most common type in the UK and are used for a range of wastewater treatments. Typical examples include tertiary wastewater treatment – removing effluents from upstream treatment processes – as well as the secondary treatment of stronger polluting liquids such as industrial or septic tank effluents. These systems are also used to treat grey water from washbasins, showers and baths, and storm waters.

A typical horizontal flow bed consists of a soil or gravel matrix in which the reeds are planted. UK systems use predominantly gravel media. The wastewater is fed onto the inlet end of the bed, flows through this matrix and emerges at the exit end of the bed. The matrix is kept flooded with the water surface less than 5 cm below the surface of the gravel media.

One recent example is a reed bed in Berkhamsted, Hertfordshire (see over page), owned by UK water company, Thames Water. Commissioned in 2008 and designed for ARM Reed Beds by one of the authors, the sub-surface horizontal flow reed bed is used for the tertiary treatment of sewage, specifically for foam and ammonia removal.

**VERTICAL FLOW REED BEDS**
If one wants to deal with stronger effluents and have less space, then vertical flow reed beds can be a better option. These systems are more complex to build than horizontal versions and the sizing of the bed area is crucial to provide treatment to specific standards.

A vertical flow system is typically 1 m deep and contains a range of matrix materials which are graded according to size. Large stones lie at the bottom of the bed, topped with smaller stones, typically 30 mm to 60 mm in diameter. Coarse gravel lies on top of this, with 6 mm pea gravel above this layer and sharp sand lying on the surface.

The wastewater is distributed across the surface and flows downward vertically through the layers of sand, gravel and stone. As with horizontal beds, the network of rhizomes maintain hydraulic conductivity as well as supporting populations of aerobic bacteria. In such a set-up, the bed is intermittently dosed with wastewater which allows time for the effluent to percolate through the matrix. As the effluent drains out, air is drawn from the atmosphere into the bed, enhancing oxygen transfer through the system. Perforated pipes, set within the layers, allow further air ingress.

This extra oxygen availability means vertical beds provide good nitrification, or ammonia removal, as well as removal of biochemical oxygen demand (BOD) pollutants. Meanwhile, horizontal flow systems are more suited to removing biochemical oxygen demand pollutants and suspended solids (Tables 1 and 2).

A vertical flow bed, also designed by ARM Reed Beds, is currently operating at Aldbrough gas storage works in Hull. Commissioned by UK-based engineering consultancy, Amecon, for use by UK electricity and natural gas supplier, Scottish Southern Energy, the system treats wastewater containing methanol and benzene.

The system was designed with a gravel matrix, planted with Phragmites australis. The bed area is relatively small, measuring 210 m² and the average flow to the bed is 0.6 m³/hr.

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**Table 1: Removal mechanisms in engineered reed beds**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Removal process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended solids</td>
<td>Sedimentation, filtration</td>
</tr>
<tr>
<td>Biochemical oxygen demand</td>
<td>Degradation to CO₂ and H₂O by microorganisms</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Main removal by nitrification-denitrification. Ammonia oxidised to nitrate by nitrifying bacteria in aerobic zones. Nitrates converted to N₂ gas by denitrifying bacteria in anoxic zones. A little removal by plant uptake and ammonia volatilization</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Adsorption, complexation, precipitation reactions within the bed matrix, particularly with Al, Fe, Ca and clay minerals. Very little plant uptake</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Precipitation reactions after pH changes, sedimentation</td>
</tr>
<tr>
<td>Pathogens</td>
<td>Sedimentation and filtration. Competition and natural die-off. Excretion of antibiotics from roots of plants and from composting of plant litter on bed surface</td>
</tr>
</tbody>
</table>

**Table 2: Removal of pollutants in engineered reed beds (based on sewage)**

<table>
<thead>
<tr>
<th>Bed type</th>
<th>Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal sub-surface flow</td>
<td>Biochemical oxygen demand is 80-90%. Total Nitrogen: 30-40%. Total Phosphate up to 25%</td>
</tr>
<tr>
<td>Vertical flow</td>
<td>For a two-stage process. Biochemical oxygen demand up to 90%, suspended solids up to 90%, ammonium compounds up to 75%</td>
</tr>
</tbody>
</table>
 Reed beds treat effluent effectively, have a broad application range, and have low or no energy requirement: as long as gravity is on your side, no power is required. They have low maintenance costs, create wildlife habitats, offer sustainability, and are very robust.

As the designs of reed bed develop and become increasingly sophisticated, more and different wastewaters are able to be treated. These include run-off from roads, airports, and vehicle-servicing areas as well as leachate from landfill sites and metal-contaminated effluents from operating and derelict mines.

Over the past 30 years in Europe, these constructed wetland systems have been successfully harnessed to treat sewage and many other pollutants in wastewaters. Without a doubt, even greater potential remains for the engineered reed beds of the future.

**HOW BIG IS A BED?**

Traditionally beds have been constructed some 600 mm deep and 10 m to 15 m long. Many designs rely on operational data and experience from previous installations.

The bed area needed is determined by the waste water flow rate and the required reduction in the polluting strength of the water, which is generally measured as biochemical oxygen demand (BOD), suspended solids (SS) and ammonia NH₄N. BOD is the amount of oxygen required by aerobic microorganisms to decompose the organic matter in a sample of water, such as that polluted by sewage. It is used as a measure of the degree of water pollution. The cross-sectional area of the bed can be calculated using Darcy’s Law which describes the flow of a fluid through a porous medium, such as a granular bed. Based on Henry Darcy’s observations (conducted back in 1856), the law relates the cross-sectional area of the bed to fluid flow rate, hydraulic conductivity, and the hydraulic gradient.

In using the bed it is recognised also that with time the bed matrix may become affected by the build-up of solids. Although there is a limited level of self-cleaning, experience over the last 20 years shows that for some installations the bed gravel may need to be removed and cleaned after 10-12 years operation.

**FUTURE DEVELOPMENTS**

Today, reed beds are seen as a sustainable way to treat sewage. The majority of the operating reed beds found in the UK are usually horizontal flow beds for the tertiary treatment of sewage at small works; however, vertical flow beds are becoming more widely used.

Now, as the industry’s understanding of design principles increases, more and more interesting treatment systems are emerging all the time.

For example, sludge-drying reed beds, a modified version of the vertical bed and widely used in Denmark, are now being built in the UK. With this design, the sludge is distributed over the surface of the bed and the solids become trapped and gradually biodegrade. Meanwhile, any liquid percolates down through the bed, receiving treatment before being returned to the bed’s inlet.

Another design, the floating reed bed, has been researched in Belgium. This consists of a buoyant, tubular framework inside which a coir mattress is fixed and across which the reeds are planted. The resulting raft literally floats on the water.

This design is ideal for anering ponds or lagoons and removing algal blooms. In fact, the beds can also be designed to encourage or dissuade nesting birds while additional wetland plants can be added to the reeds to promote insect diversity.

**TICKING ALL THE BOXES**

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As the designs of reed bed develop and become increasingly sophisticated, more and different wastewaters are able to be treated. These include run-off from roads, airports, and vehicle-servicing areas as well as leachate from landfill sites and metal-contaminated effluents from operating and derelict mines.

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