The Chemical Engineer, 2010, issue 833, pages 38-39

Anaerobic workout

Could sewage treatment follow the lead of food and drinks manufacturing in reducing energy demands? Yes, says **Ewan McAdam**

FOR the past decade, the food and drinks industry has embraced high-rate anaerobic wastewater treatment as a way of reclaiming energy, in the form of methane, from low-flow wastewaters that are rich in soluble organic carbon. By contrast, major water utilities still mainly use aerated processes in their sewage treatment to reduce organic carbon to carbon dioxide.

The energy required for aerated systems is currently ~55% of the total energy demand of a water treatment plant, which corresponds to ~0.65 kWh/m^3 of treated wastewater. Anaerobic reduction of organic carbon proceeds in the absence of air, thus creating a direct energy saving. In addition, organic carbon is reduced to methane as the predominant gaseous end-product, which can be used for electrical generation. The translation of anaerobic technology by water utilities therefore presents a lateral, and significant, commercial opportunity, particularly with respect to lowering net energy demand and overall carbon footprint.

At Cranfield University's Centre for Anaerobic Science, we've made significant progress in understanding the complex transfer of knowledge to low-temperature, low-organic strength feedwaters:

process integration

In contrast to food and drinks wastewaters – which typically have low volumes of liquid, moderate temperatures of 28–32°C and high organics concentrations up to 50,000 mg/l – combined sewers in Europe generate high volume, low-temperature (UK mean 12°C), dilute organic wastewaters with organic concentrations up to 500 mg/l. Based upon these limiting factors it's been a long-held perception that domestic wastewater cannot be treated anaerobically since low organic substrate concentration and temperature will limit the microbial kinetics, leading to bacterial washout, insufficient organic biodegradation and low methane gas production. However, process intensification using high-rate reactor concepts such as upflow anaerobic sludge blanket reactors (UASBs) or anaerobic membrane bioreactors (anMBRs) have greatly advanced the potential of low temperature anaerobic treatment by separating biomass retention from hydraulic retention times (HRT). The result is an engineered environment that combines a high density of slow-growing bacteria with high organic loading rates.

Further process intensification of the UASB process has also been pioneered at Cranfield, using a concept called "fortification" which facilitates the separation of organic loading rate from HRT. This provides the capacity to increase the biological kinetics in co-operation with an extended reaction time, resulting in increased methane production. Nevertheless, due to the lower kinetic rates at low temperature, it's only by using the physical retention afforded by the membrane in the anMBR that the produced effluent can meet the UK wastewater discharge consent for organic carbon.

The upflow anaerobic sludge blanket (UASB) reactor configuration removes slightly less organic carbon by comparison as the process relies on lamella separation for passive clarification rather than using fine pores like anMBR. This means that UASBs require a further downstream unit process to remove enough organic carbon removal to meet consent. Importantly, process modelling has demonstrated that whilst UASB configurations suffer from reduced treatment performance, integrating an UASB upstream of a conventional activated sludge process (ASP) in a conventional flowsheet under UK conditions can cut energy demand (inclusive of aeration) by around two thirds.

By contrast, whilst anMBR can operate as a single unit process for organic carbon removal, the membrane surface has to be cleaned using gas sparging to limit surface deposition, which requires extra energy. Our research suggests potential for major reductions in parasitic energy demand for the membrane process; however, at present the net energy balance does favour the uptake of UASB technology which will require downstream biological organic carbon removal.

> *The translation of anaerobic technology by water utilities presents a lateral, and significant, commercial opportunity*

In reality, it's unlikely that one fixed flowsheet configuration will prevail, due to a complex number of variables surrounding implementation at full scale. Consequently, while this research continues, we are evaluating a number of flowsheets.

downstream organic and nutrient removal

At full scale, both nitrogen and phosphorus may have to be removed from the effluent of the anaerobic processes to meet consent. For classical biological unit processes incorporating aeration (eg ASP), nitrogen and phosphorus loads can be removed in addition to organic carbon in the single unit process. However, using UASB or anMBR avoids aeration, which in turn stops nitrification (the stoichiometric conversion of ammonia to nitrate in the presence of oxygen). Therefore, based on current practice for wastewater treatment, further downstream biological treatment must be used to achieve consent.

One can demonstrate the significance of nitrogen removal on total energy demand using the UASB-ASP flowsheet as an example. Since UASB has removed the principal organic load, the flowsheet shows that aeration to support downstream nitrification within the ASP becomes the predominant parasitic energy demand. A more sustainable route to minimise the internal parasitic energy demand for nitrogen removal is therefore to integrate passive aeration units downstream of the anaerobic process (eg trickling filters). The impact on the net energy balance is significant: switching to passive downstream treatment turns wastewater treatment from an energy user into an energy producer and gives the industry the potential to export electricity to the grid. However, trickling filters can become unstable at lower temperatures which risks failure to comply with discharge consent during the winter.

In addition, we have considered the argument that using biological processes to remove nutrients neglects the potential use of nutrients in secondary applications. We have extensively trialled cationic and novel polymeric anionic exchange resins bound with ferric oxide for the selective extraction of ammonia and phosphorus from anaerobic effluents into low volume, high concentration solutions.

The parasitic energy demanded by physcio-chemical nutrient recovery is low. However, the combination with upstream anaerobic treatment produces the greatest synergies using anMBR since that process won't use secondary biological processes to remove of residual organics to conform with consent (see Figure 1). This movement toward nutrient recovery not only offers scope to reduce energy demand over conventional aerated processes, but since in both base chemicals currently cost arou[illegible]350/t, there is more money to be saved via recovery.

Current trials have demonstrated effective separation in environmentally-relevant matrices, and have illustrated that low parasitic energy demand can be achieved. Further research will look at ways to cut costs by minimising the chemicals needed to regenerate the ion-exchangers. We also need a higher-level techno-economic assessment of the various nutrient end-products to decide whether the chemicals should be packaged as a dissolved solution, precipitate or stabilised in a crystal form called Struvite.

dissolved gas recovery

Lower temperatures increase the solubility of dissolved gases, in accordance with Henry's law. In anaerobic wastewater treatment, this matters, because when untreated wastewater is cold, methane becomes more soluble and more will escape in the treated effluent. Therefore whilst implementing UASB can considerably lower net energy demand of the conventional wastewater flowsheet by reducing aeration demand and producing methane, methane yield can be increased by another 100% by recovering dissolved gases from the treated effluent.

To recover the dissolved gases, we designed a hollow fibre membrane process to selectively extract methane from the effluent to form a concentrated gas phase. We can produce enough energy from the recovered dissolved methane to offset the parasitic demand of the UASB-ASP flowsheet, so we can still have an energy-positive wastewater treatment process without coupling to nutrient recovery or passive secondary treatment.

We have shown that the process is effective at bench scale, though further work is needed to validate gaseous separation over long-term operation where biofouling has the potential to reduce gaseous mass transfer across the membrane interface.

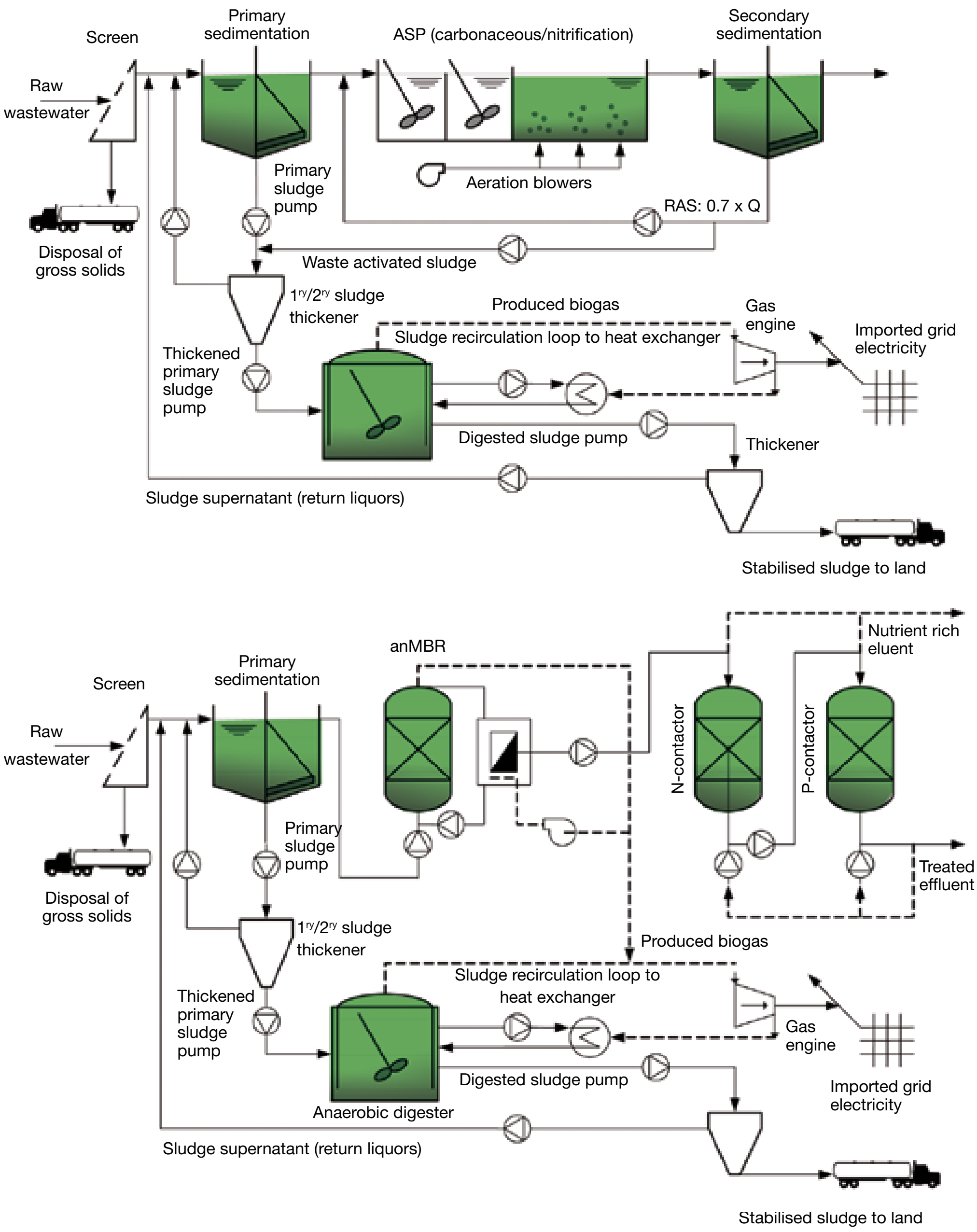

Figure 1: Conventional wastewater flowsheet comprising an aerated activated sludge process (top) versus an alternate flowsheet proposed by Cranfield comprising anMBR followed by physico-chemical recovery of ammonia and phosphorus (bottom).

conclusion

Anaerobic technology may not be able to replace to current wastewater treatment processes. Instead, we should consider a more holistic approach comprising secondary unit processes to meet consent. Novel secondary technologies increase both the environmental and economic horizon by realising energy positive wastewater treatment and the potential to generate new product streams. Significantly, this concept marks the transition from wastewater treatment focussed on environmental pollution toward a new chemical engineering paradigm which delivers significant economic benefit through the production of excess electricity and base fertiliser chemicals for export. **tce**

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2010-11-30T00:00:00Z

Ewan McAdam. Anaerobic workout. TCE - The Chemical Engineer, 2010, issue 833, pages 38-39
http://dspace.lib.cranfield.ac.uk/handle/1826/8459