Esholt WwTW Bio-Energy Installation

optimising the production and utilisation of biogas from sewage sludge

by Peter Bense MA CEng FEI FIMechE

Esholt WwTW, located to the north of Bradford, is one of the largest wastewater treatment works in Yorkshire. The site serves a population equivalent of some 760,000 from Bradford and the surrounding area treating both indigenous and imported sludge streams. Historically around 40% of the sludge received was treated by incineration. This is highly energy intensive relying on the use of oil fuel to support the incineration process. The increasing costs of the support fuel, together with the associated carbon emissions, have prompted Yorkshire Water (YW) to review their sludge strategy and look for alternatives to the incineration process.

Energy centre with 2 (No.) new 1,600 KW engines in place - Courtesy of Yorkshire Water

Background

YW recognise that the sludge import is a potentially valuable fuel source and, as part of a general expansion and update of the works, have implemented a project to maximise energy recovery and the economic returns this brings. A key part of this project is the adoption of an advanced anaerobic digestion (AAD) process using thermal hydrolysis to treat the sludge before digestion.

The Thermal Hydrolysis Process (THP) involves heating the sludges under pressure to a temperature in excess of 160ºC for 30 minutes then rapidly depressurising. This causes the cellular structure of the sludge to disintegrate making it more easily digestible resulting in a considerable increase in biogas production. An additional benefit is that the treated sludge is effectively pasteurised allowing it to be used on land as a fertiliser or soil conditioner.

Renewable Obligation Certificates

Generation of electrical power from renewable sources such as biogas qualifies for incentive payments under the UK Renewables Obligation. Incentive payments are made in the form of Renewable Obligation Certificates (ROCs), which can be traded on by the producer and have a value determined by the market at the time. Typically a ROC is worth £40-£50 per Megawatt hour (MWh) of electricity generated. ROCs are claimable on the electricity generated irrespective of whether it is used on or off site. In addition to the incentive payments, any power generated has a value either in avoiding the cost of imported electricity or in direct sale as export into the national grid.

Undertakings

The Morgan Sindall Grontmij Joint Venture (MGJV) one of YW's large scheme delivery partners, was selected to design and deliver modifications to the plant to implement this revised strategy. This included modifications to the treatment process with the associated plant and infrastructure together with an additional anaerobic digester and extensive modifications to the existing sludge handling facilities.

Design of the energy plant

The THP process installed at Esholt is a *Biothelys* plant supplied by Veolia Water Solutions. Sludge is processed in three pairs of reactors operating as a sequenced batch process. Heating of the sludge within the reactors is carried out by injecting steam at a pressure of around 7 barg.

Steam is not normally used on traditional wastewater treatment sites. In order to provide this at Esholt it was necessary to design and construct a new energy centre and to train the site operating staff in the practical and statutory aspects of owning and operating steam boiler plant.

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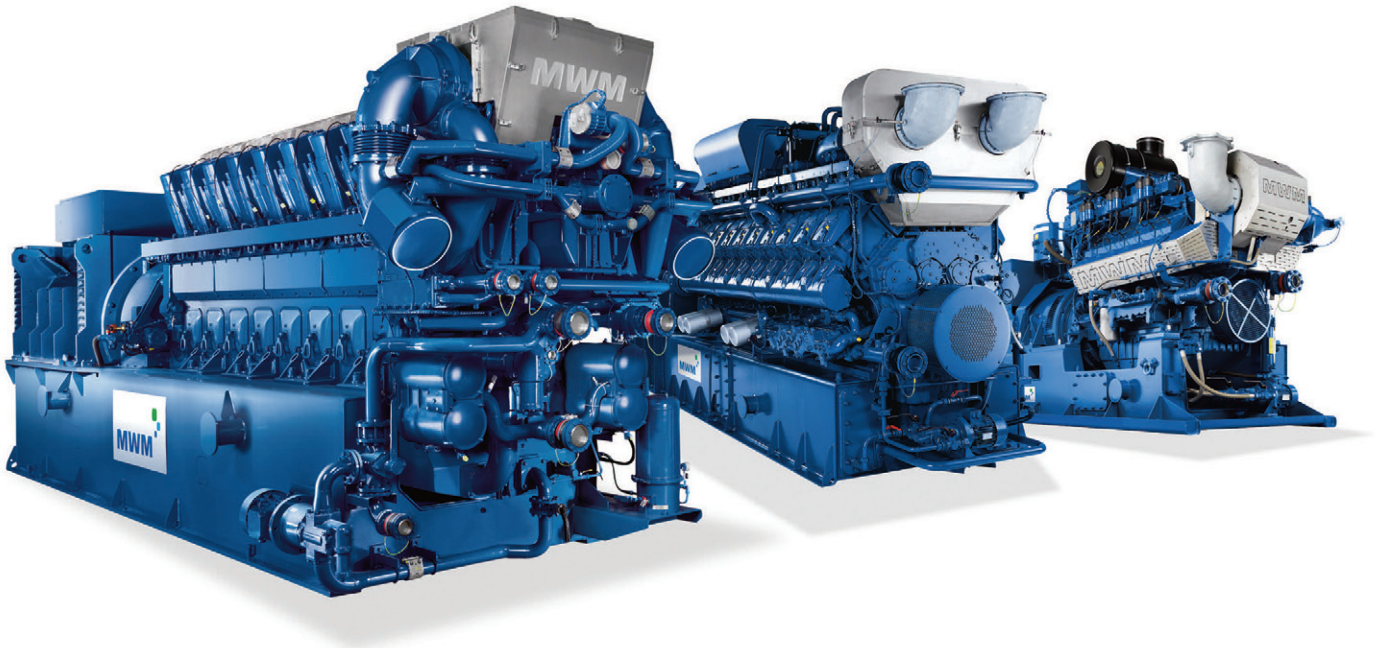

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Steam is generated in the boiler plant using a combination of the heat recovered from the exhaust of the engines and a supplementary fuel. The costs of the supplementary fuel are a major factor in determining the overall plant operating cost.

Given the ongoing uncertainty surrounding long term fuel, energy costs and incentive levels it was essential that the steam generation plant be designed to give the maximum flexibility in operation. The aim was to allow YW to adjust the operating parameters whenever required to optimise revenue by selecting the most cost effective fuel source at any given time or by maximising electrical generation during periods of high electricity value.

One of the key design requirements for the energy centre was that generation of renewable electricity from the available biogas should be maximised. Prior to the installation of the THP plant this generation was carried out by 2 (No.) 600KW gas engines.

These engines were commissioned in March 2011 under the AMP4 cycle and as such qualify for an enhanced ROC entitlement of 1 ROC/MWh. The ROC entitlement for sewage gas based generation plant installed after this date has been halved to 0.5 ROC/MWh.

However offsetting this, improvements in gas engine technology have significantly increased the efficiency of modern engines. There is therefore a balance to be struck between the use of relatively inefficient engines at a high incentive rate, or higher efficiency engines receiving reduced incentives.

Process modelling

To start the design process Grontmij created a whole-site energy model. This allowed a virtual system to be built up using different plant configurations, where the quantity, type and size of engines and boiler plant could be varied. The performance of the virtual system was then analysed by adjusting the process parameters, such as biogas production and quality and THP process steam demand to determine the practical operating envelope.

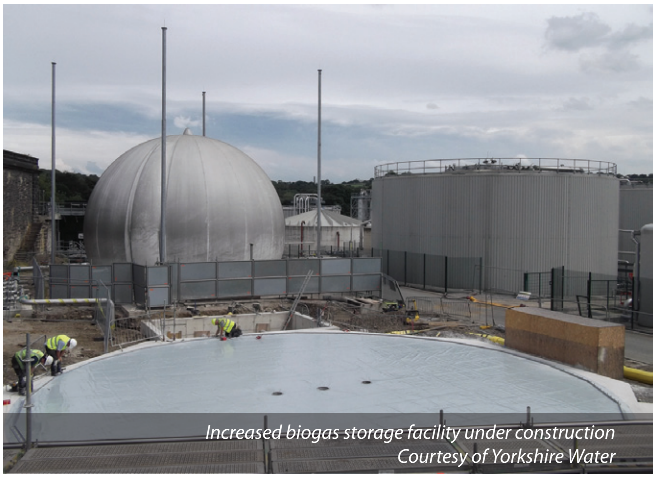
As part of this it was necessary to consider off design operation of the process, as would occur for example during maintenance of the THP plant when steam demand would be significantly reduced. Similarly it was necessary to incorporate sufficient redundancy and stand by capacity into the energy centre to ensure reliability of the steam supply to the process.

Having determined that the proposed system was physically capable of supplying the required process demands under all of the anticipated operating conditions a further analysis was carried out to determine the optimum method of operating the proposed plant to maximise revenue. This incorporated a sensitivity analysis of the effects of variation in key economic parameters such as fuel prices, ROC incentive levels, electricity costs and costs of carbon emission payable under the Carbon Reduction Commitment (CRC).

The model results were used to predict the revenue from the proposed energy centre. These predictions were used to develop the business case used by YW's management in making the decision to proceed with the project.

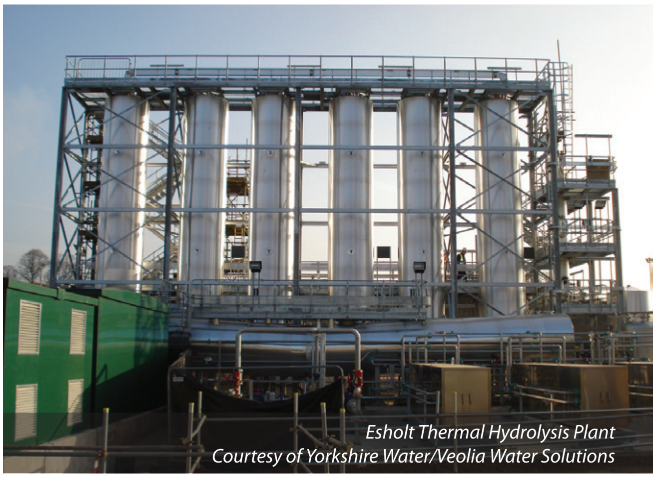
Final design

The final design of the energy plant consisted of two new MWM gas engines supplied by Edina UK each having a rated output of 1,600KWe. Each of these engines was coupled to a dedicated composite boiler designed to recover the heat in the engine exhaust gas and supplement this by burning either gas oil or biogas in a conventional fired section. Each of the boilers was rated to produce the steam required at full THP load without any contribution from engine waste heat. The composite boilers were fitted with engine exhaust gas bypass systems, allowing the engine operation to be decoupled from the steam demand when necessary.



Increased biogas storage facility under construction Courtesy of Yorkshire Water

Existing AMP4 engine installation. New gas holder & waste gas burner In background - Courtesy of Yorkshire Water



Esholt Thermal Hydrolysis Plant Courtesy of Yorkshire Water/Veolia Water Solutions

Boiler house showing composite & waste heat boilers Courtesy of Yorkshire Water/MGJV /Cofely

The 2 (No.) existing 600KW engines were retained and coupled to a common waste heat recovery boiler. The virtual plant model was used to determine the benefit of fitting engine exhaust gas bypass systems to this boiler and concluded that the additional cost of fitting these could not be justified.

Following concept design by MGJV the contract for detail design and supply of the boiler house internal equipment and systems was let to Cofely.

The final arrangement comprised a total generation capacity of 4,400KWe and a steam generation capability of in excess of twice the THP process demand. The steam generation can be decoupled from the engine operation. This is particularly important during plant commissioning as it allows steam to be provided to the THP plant early in the programme before the engines are operational. The existing engines will continue to operate in their original configuration elsewhere on the site until the new engines are available. They will then be relocated to the new energy centre.

If all engines are operating at full output the biogas consumption is greater than the predicted maximum production from the site. As part of this project the site biogas system was extended to incorporate gas storage equivalent to around three hours at maximum biogas generation. By managing this storage YW will be able to boost generation at times when the cost of electrical import to the site is high, for example during peak or triad charging periods.

During these periods the supplementary fuel to the boilers will be gas oil, maximising the amount of biogas available for use in the engines. At times when the value of generation is low, or due to engine maintenance the full biogas consumption capacity is not available, any surplus biogas can be diverted to the boilers reducing the demand for gas oil.

One issue that was identified during the design was the need for the boiler plant to be capable of providing steam at times when the THP plant is operating at low load. Under normal circumstances the reactors operate in sequence, and this is timed to provide a fairly steady steam demand. However if one pair of reactors is off line, for example during maintenance periods, the steam demand becomes a step change from effectively zero to 100% over a very short period. There was a concern that this sudden change could cause instability in the boiler system.

To address this a second dynamic model of the boiler system was developed and a number of control algorithms tested. The result was the development of a feed forward control which allows the boiler system to prepare itself for sudden changes in steam demand.

The THP plant is currently under commissioning. The throughput is slowly being increased as the digesters are progressively changed from the original feedstock to hydrolysed sludge. The new engines are installed but not yet commissioned and to date the boiler plant has been producing the steam required for the THP plant commissioning using gas oil. The feed forward control concept has been proven with the observed system behaviour agreeing well with the theoretical model.

Conclusion

At the time of writing (July 2013) all of the biogas produced is being consumed by the original engines, as the proportion of hydrolysed sludge in the digesters builds up the biogas production will increase and the new engines will be commissioned. This will allow the older engines to be relocated and the energy centre to be fully commissioned.

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Boiler Control System
Courtesy of Cofely

Boiler house showing composite & waste heat boilers
Courtesy of Yorkshire Water/MGJV /Cofely