WWTW design

Achieving optimum energy efficiency

Constraints around security and the affordability of energy are increasingly driving planning decisions in municipal water and sanitation service provision. **By Daniel J Petrie et al.***

SOUTH AFRICA HAS experienced a shortage in base load electricity supply in recent years, prompting Eskom to demand significant increases to the bulk price of electricity in order to finance new capital expansion projects. Wastewater treatment is typically one of the most energy-intensive activities mandated to local municipalities. As the electricity price in South Africa increases, some local authorities have begun to explore ways to reduce energy costs through enhancements to treatment infrastructure.

The recent trend at wastewater treatment works (WWTWs) in industrialised nations has been to reduce energy costs by implementing technologically complex energy-efficiency or energy recovery solutions that achieve significant reduction in net energy use, but which are associated with high upfront capital investments and onerous operating and maintenance requirements.

To date, there has been much debate in the municipal engineering sector regarding the realistic potential of implementing energy-efficiency objectives in wastewater treatment. To shed some light on the matter, a study was conducted to test the technical and economic potential of different energy-efficient solutions across a range of scales of Western Cape WWTWs and determine what process enhancements

Zandvliet Pump Station

TABLE 1 Description of WWTWs investigated

WWTW	Authority	Technology	Rated capacity (2015/16)	Status
Zandvliet	City of Cape Town	MBR and BNR/SST	72 Mℓ/day	Upgrade under way (capacity limited)
Malmesbury	Swartland LM	MBR	10 Mℓ/day	Upgraded 2013
Riebeek Valley	Swartland LM	BNR/SST	2 Mℓ/day	Upgraded 2016
Darling	Swartland LM	BNR/SST	1.5 Mℓ/day	Due for upgrade (capacity limited)
Moorreesburg	Swartland LM	Extended aeration / SST	1.5 Mℓ/day	Due for upgrade (ageing infrastructure)

(if any) could feasibly be implemented at each scale.

This study incorporated work undertaken for the City of Cape Town and the Swartland Local Municipality during two different planning studies for upgrades to five WWTWs, as listed in Table 1. A broad spectrum of wastewater treatment technologies was assessed, from a simple base-case scenario to a more sophisticated scenario for each of the treatment works considered within the study. For each case study, projections were made of future flows as well as organic and nutrient loads. The associated key treatment plant design parameters were then determined using steady-state biological treatment process models. The outputs from the technical models were then used to develop a comparative economic model, to assess the life-cycle costs of the different options at each WWTW.

The determination of energy savings achieved by improvements to the treatment processes at each WWTW involved the following sequential modelling and calculation steps:

- Conceptual design of incremental improvements to treatment process configurations
- Analysis of historical influent data and projections of the future flows and organic and nutrient loads expected at each WWTW
- Activated sludge modelling of each WWTW considering capacity upgrades and different treatment configurations
- Sludge handling and beneficiation modelling at each WWTW considering: biogas generation potential and energy recovery, net electrical energy use, and fuel energy for sludge transportation

The treatment process configuration has a significant impact on the overall energy-efficiency of the WWTW, most significantly due to the aeration requirements of biological treatment processes for the removal of organics and nutrients, as well as the pumping of wastewater flows, and sludge handling and beneficiation. Eight case study treatment process configurations were considered at each treatment works, as summarised in Table 2.

Not all options were considered for each treatment works. For instance, the larger works are already equipped with fine-bubble diffused aeration systems. For these plants, Option 1 is therefore adopted as the 'baseline'. The options to compost sludge were also not considered in the case of Zandvliet WWTW, where close proximity to residential neighbourhoods and heavy winter rainfall would make such a technology impractical.

Results: Zandvliet WWTW

The results from Zandvliet WWTW indicate that significant energy savings can be enjoyed by adopting more sophisticated treatment options. Given the size of the Zandvliet works, any marginal savings equate to significant energy savings in absolute terms.

While composting options were not considered here, Option 4 (see Table 2) demonstrates a significant reduction in overall plant energy consumption, primarily because installing PSTs will liberate capacity in the existing conventional BNR stream, which is less energy intensive than the existing and proposed MBR streams, reducing the energy required for membrane pumps as well as for aeration.

By recovering energy from the digester biogas (option 5), the plant can achieve a net saving of over 70% against the baseline scenario, and by including pre-treatment and advanced digestion (option 6) this can be augmented further to over 80%. Option 7, on the other hand, incurs a significant energy penalty associated with the transportation of dewatered sludge.

While the 'business-as-usual' scenario (option 1) and installing PSTs and mesophilic digestion are the most affordable in terms of capital expenses, they are expensive in terms of OPEX, mostly due to high energy and sludge disposal costs.

In contrast, the options that involve recovery of energy are expensive in terms of CAPEX, but are significantly cheaper to operate.

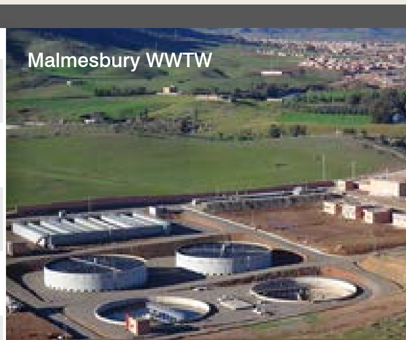
For the case of large WWTWs, such as Zandvliet, the more sophisticated solutions (Options 5 and 6) are economically optimal when assessed over a 25-year planning period. In addition, the overall economic performance of the works is influenced more by the cumulative effects of operating expenses over time than by the initial capital outlay.

Results: Malmesbury WWTW

The results from Malmesbury WWTW confirm that, at larger works that use MBR

TABLE 2 Matrix of options considered at each WWTW

Option	Consideration	Zandvliet	Malmesbury	Moorreesburg, Darling & Riebeek Valley
Option 0	Surface aeration and WAS landfill	n/a	n/a	Baseline
Option 1	FBDA	Baseline	Baseline	✓
Option 2	WAS composting	n/a	✓	✓
Option 3	Primary settling and WAS and PS composting	n/a	✓	✓
Option 4	WAS and PS mesophilic anaerobic digestion and gas flaring	✓	✓	✓
Option 5	Biogas cleaning and energy recovery (CHP)	✓	✓	✓
Option 6	Advanced digestion (pre-treatment & additional dewatering)	✓	✓	✓
Option 7	Centralised advanced anaerobic digestion (pre-treatment and additional dewatering)	✓	✓	✓


Malmesbury WWTW


Moorreesburg WWTW

technology, significant energy savings can be enjoyed by adopting more sophisticated treatment options.

The net effective energy use of each of the treatment process options at Malmesbury WWTW came to a final estimated capacity of 21 Mℓ/d (in the year 2045). By installing PSTs (option 3), the plant's energy demand can effectively be halved, while recovering energy from the digester biogas (options 5/6/7) can achieve a net saving of over 70% against the baseline scenario.

The additional CAPEX required for more complex options results in process efficiency and reduced OPEX, primarily due to the reduced costs of sludge disposal and reduced energy costs. In terms of long-term feasibility, the economically preferred solutions are options 3, 5 and 7. This confirms the major influence of energy costs on overall economic feasibility for larger plants.

The economic feasibility of centralising the sludge treatment plant at the nearby Highlands landfill site (option 7) is further confirmed for Malmesbury WWTW. However, for this option to be viable, it needs to be proven for all of the Swartland WWTWs.

Results: smaller Swartland WWTWs

The smaller WWTWs in Swartland (Moorreesburg, Darling and Riebeek Valley) exhibit similar technical results to one another, all achieving relatively large reductions in energy demand. However, given the scale of these plants, this does not translate to significant reduction in absolute terms.

The results suggest that adopting more complex treatment technologies has the potential to reduce energy demand significantly when compared with the baseline scenarios. However, there are practical limitations to implementing some of these technology options at this scale. It is, therefore, only worthwhile to consider options 1, 2, 3, 4 and 7 as being technically feasible.

In comparison to the larger works assessed, these treatment works spend a greater proportion on maintenance, labour and sludge disposal than on energy. The relative benefit of implementing energy-efficient treatment technologies is, therefore, less pronounced.

The figures also indicate that, at the smaller WWTWs, savings in energy costs are almost perfectly offset by increased maintenance costs. While economically equivalent, this shift represents an opportunity for social and environmental benefit, as money is directed to the service sector of the economy, rather than to the extractive/energy sectors.

For the smaller treatment works, the relative influence of CAPEX on overall life-cycle costs is greater than for the larger WWTWs. It is also apparent that, while installing fine-bubble diffused aeration, composting sludge, and installing PSTs are technically and economically beneficial in the long term, more advanced options are less promising economically.

Conclusions

The results of the study indicate that an optimum energy-efficient process configuration is achieved for the smaller regional treatment works (less than 5 Mℓ/d to 10 Mℓ/d) when they are designed to allow for fine-bubble diffused aeration, primary settling, and composting of sludge to achieve a stable biosolid suitable for application to fallow land.

For the larger works, the optimum is achieved by the incorporation of further advanced process technologies, including sludge pre-treatment and energy recovery from anaerobic digester gas.

Given the high costs associated with transporting dewatered sludge over long distances, the economic feasibility of centralising energy recovery within a single regional facility is limited, but is still shown to be preferable to the baseline scenarios, where sludge is transported for disposal at landfill. 3S

References available on request.

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