**Investigation of control and on-line optimisation opportunities of a wastewater treatment plant**

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**Highlights**

* A Mixed Integer Linear Programming approach is applied to Biogas Production
* Retrospective Optimisation reveals potential annual savings of over 11%
* An optimal operational strategy is provided for plant operators

**1. Introduction**

Northumbrian Water (NW) anaerobically digests up to 40,000 tonnes of sewage sludge (dry solids) annually at their plant on Tyneside, producing renewable Biogas. Typically, Biogas produced on a wastewater Anaerobic Digestion (AD) plant in the UK is used to generate electricity only. Many sites are looking to upgrade to produce Biomethane for injection into the National Gas grid to take advantage of the government’s Renewable Heat Incentive [1]. The Tyneside Advanced Anaerobic Digestion (AAD) plant is a rare case in that it has three possible uses for Biogas produced on site: upgrade for injection into the national gas grid; burning it in Combined Heat and Power (CHP) Engines; or burning it in Steam Boilers for the thermal hydrolysis plant. There are three CHP Engines, three Steam Boilers and one Gas Upgrade/Injection plant on site. If required, the plant may flare excess biogas. In addition, to ensure overall sludge processing remains unimpeded the plant may draw Natural Gas from the national gas grid to be used in the CHP Engines or Steam boilers.

Currently, there is no model on site to advise the optimal distribution of Biogas produced or how much Natural Gas is required to be purchased to ensure optimal cost and sludge processing performance. This work develops an optimal site gas distribution strategy, to enable operators to validate and make improved decisions.

**2. Methods**

Each unit is able to process a maximum volume of Biogas or Natural Gas on a daily basis. These processing limits were determined thorough retrospective analysis of plant operational data and are different for Biogas and Natural Gas volumes. Work reported in [2] was adapted to apply a Mixed Integer Linear Programming (MILP) approach to minimise total plant operational cost, TC:

$$T\_{c}= \sum\_{t=1}^{H\_{t}}(C\_{b} B\_{CHP}z\_{i})+\left(C\_{n}N\_{CHP}\left(1-z\_{i}\right)\right)+\sum\_{t=1}^{H\_{t}}(C\_{b} B\_{S}z\_{i})+\left(C\_{n}N\_{S}\left(1-z\_{i}\right)\right)+\sum\_{t=1}^{H\_{t}}(C\_{I} B\_{I} +\sum\_{t=1}^{H\_{t}}(C\_{f} B\_{f})$$

$C\_{b} C\_{n} C\_{I}$ and $C\_{f} $is the cost of burning Biogas, Natural Gas, Biomethane Injection and flaring Biogas retrospectively, $B\_{CHP} B\_{S} B\_{I} $and$ B\_{f}$ are biogas volume to CHP Engines, Steam Boilers, Injection and Flaring respectively, $N\_{CHP} $and$ N\_{S}$ are Natural Gas to CHP Engines and Steam Boilers respectively, and $z\_{i}$ is a binary variable used to ensure only one of each gas type is used by each unit, subject to $z\_{i}\in \left\{0,1\right\}, (∀ t=1…H\_{t})$, where $H\_{t}$ is the operation horizon in one day intervals.

The optimiser was implemented using MATLAB’s *intlinprog* function to minimise plant costs.

**3. Results and discussion**

The optimiser takes total daily biogas production on site and optimises the overall gas distribution, providing the operator with a visual operation strategy (Figure 1). Each daily optimisation also has an associated operational cost, which is used to perform Retrospective Optimisation (RO) of plant operations.

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| **Figure 1.** Optimal Gas Distribution on site for daily production of 50,000 Nm3 of Biogas | **Figure 2.** Daily RO result over 12 month period. 0% Difference is optimal. Red dots indicate days where flaring occurred but was unnecessary. Green dots indicate optimal performance. |

RO of the daily optimal operational cost compared to the actual historical operational cost was performed for the 12 month period Nov 2017 to Oct 2018 (Figure 2). Initial RO results indicate potential annual operational cost savings >11% (>£0.5m). At times the plant operates more efficiently than the optimiser predicts. This is due to the static nature of model parameters that are an average of overall annual performance, and will be rectified in future work.

**4. Conclusions**

Our work indicates there are potential annual savings of over 11% to operational costs that could be achieved through improved operational strategies; the daily optimal operation strategy is provided to the operators in visual form, though weekly strategies are also possible if required. Further work is to be carried out to provide operators with a full sludge processing optimisation model, including a biogas production model to allow for improved operational forecasting.

**References**

[1] M. Hale, Maximizing biomethane use in sewage plants, Filtr. Sep. 54 (2017) 26–27. doi:10.1016/S0015-1882(17)30082-4.

[2] T. Cummings, R. Adamson, A. Sugden, M.J. Willis, Retrospective and predictive optimal scheduling of nitrogen liquefier units and the effect of renewable generation, Appl. Energy. 208 (2017) 158–170. doi:10.1016/j.apenergy.2017.10.055.