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

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Stream

The Industrial Doctorate Centre for the Water Sector

Introduction and Aim

- Northumbrian Water (NW) anaerobically digests up to 40,000 tonnes of sewage sludge (dry solids) annually at the Advanced Anaerobic Digestion (AAD) plant [Fig.1] at Tyneside, producing renewable 'Biomethane' (Biogas). The site also processes up to 12,000L/s of raw sewage a day [Fig.2].
- **Aim**: To investigate and develop operational strategies (process control and optimisation) in order to improve process understanding, operation and site robustness.

Figure 1 – Areal Photograph of sludge processing area of Tyneside Wastewater Treatment Facility, Newcastle

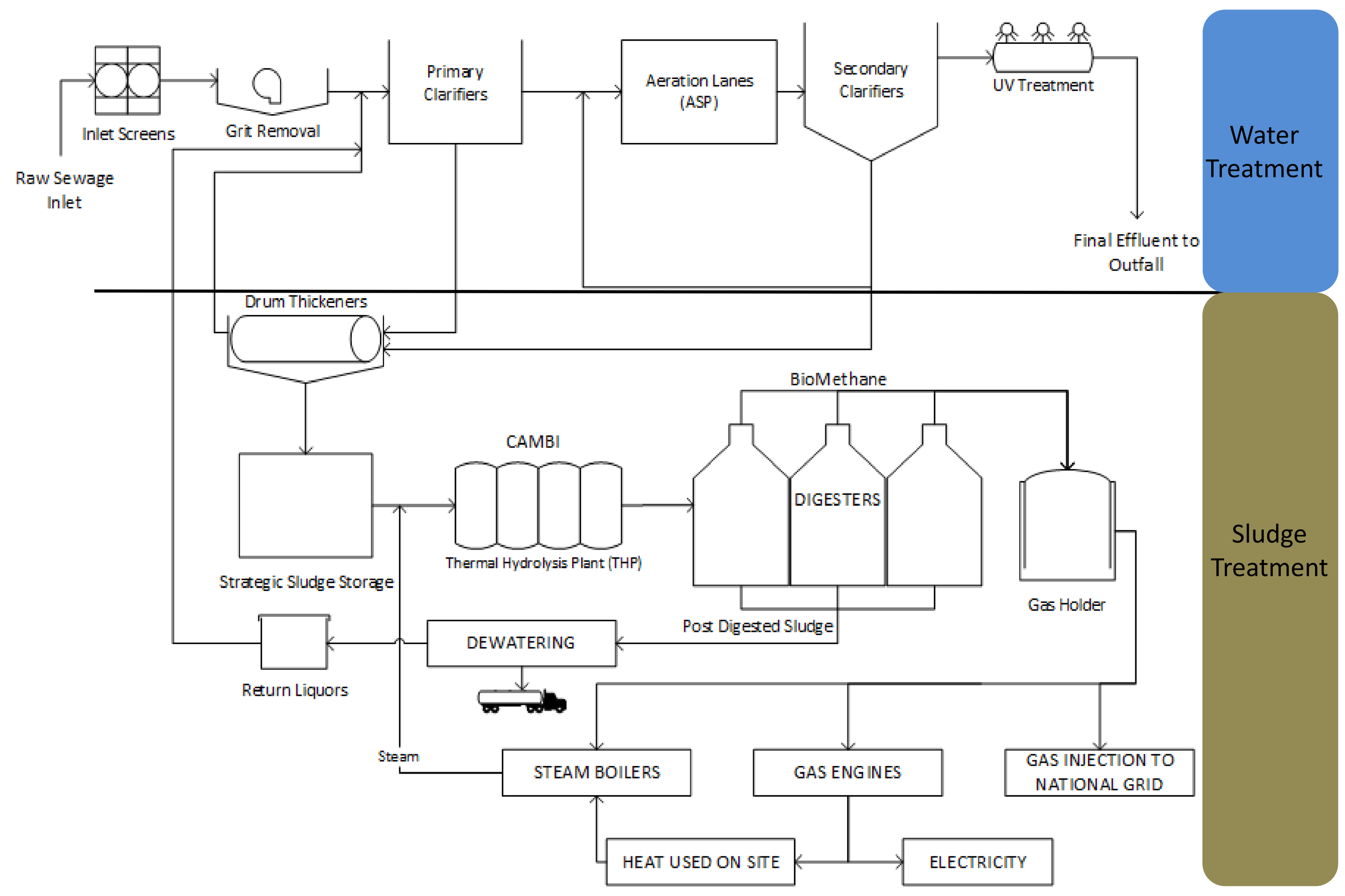

Figure 2 – Overview of Sewage Processing at Tyneside Wastewater Treatment Plant

Case Study 1

- It was hypothesised that improved operational scheduling of the 'Dewatering' process [Fig. 3] of the AAD plant around fluctuating electricity costs could have significant savings; the power consumption of the centrifuge is large (196kW) and it runs for long periods of time.
- Adapting work carried out by Cummings *et al.* [1], the operation time of the centrifuge was modelled as binary variable in a Mixed Integer Linear Programming (MILP) problem statement:

Key:
c_t = Electrical tariff price
P_t = Power Consumption
T_c = Total Cost
w_t = 15 minute operation

$$T_c = \sum_{t=1}^{N_t} c_t \, . P_t \, . w_t$$

$$w_t \in \{0,1\}, (\forall\, t = 1 \dots N_t)$$

- Historical operational data was available for April 2016- April 2017. An example 10 day period of how the process was run is shown in Figure 4 and the Optimised schedule in Figure 5. Annual Electrical Savings of over £18,000 per annum could be made though scheduling improvements.

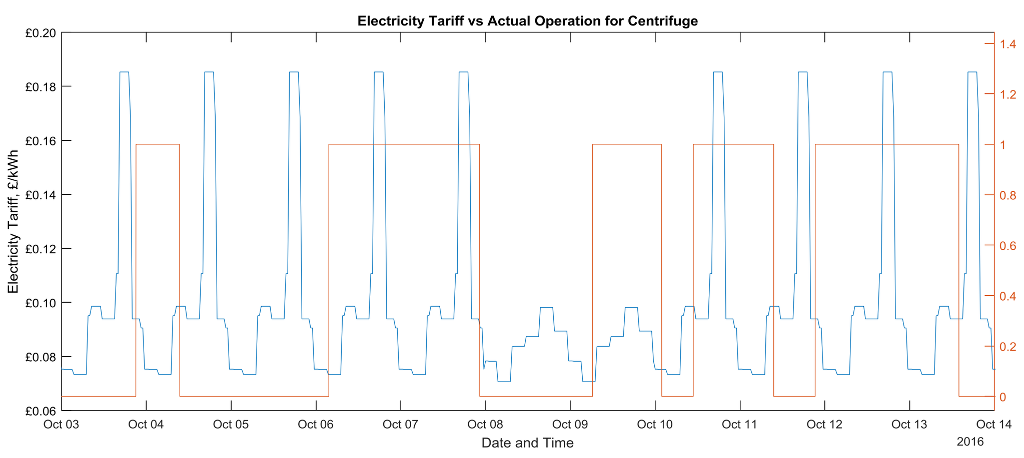

Figure 4 –Actual Operation of Dewatering Centrifuge (Electricity Tariff in blue for reference)

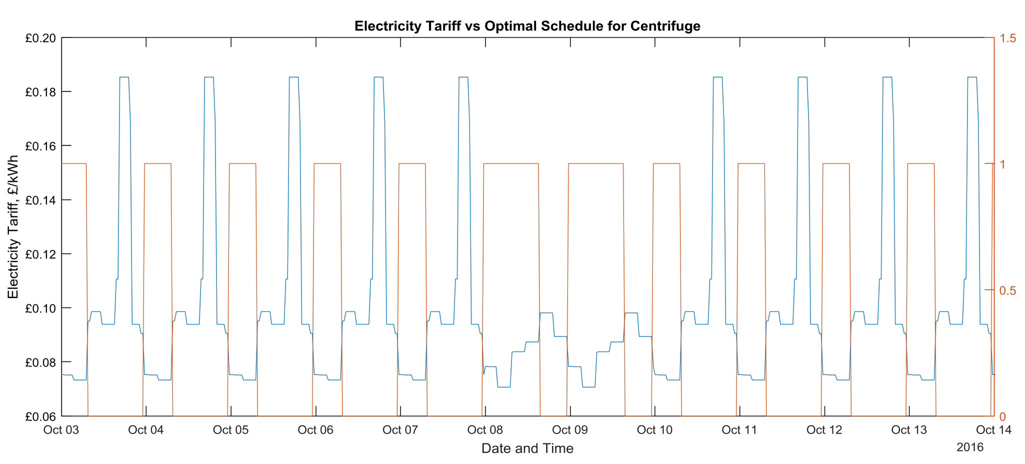

Figure 5 –Optimised Schedule of Dewatering Centrifuge (Electricity Tariff in blue for reference)

Case Study 2

- Northumbrian Water has three options with regards to Biogas produced on site: Injection into the National Grid, burning it in their CHP Engines to make electricity, or burning it in their Steam Boilers.
- The CHP Engines and Steam Boilers must be utilised, and can have either Biomethane OR Natural Gas as a fuel source, but not both at once.

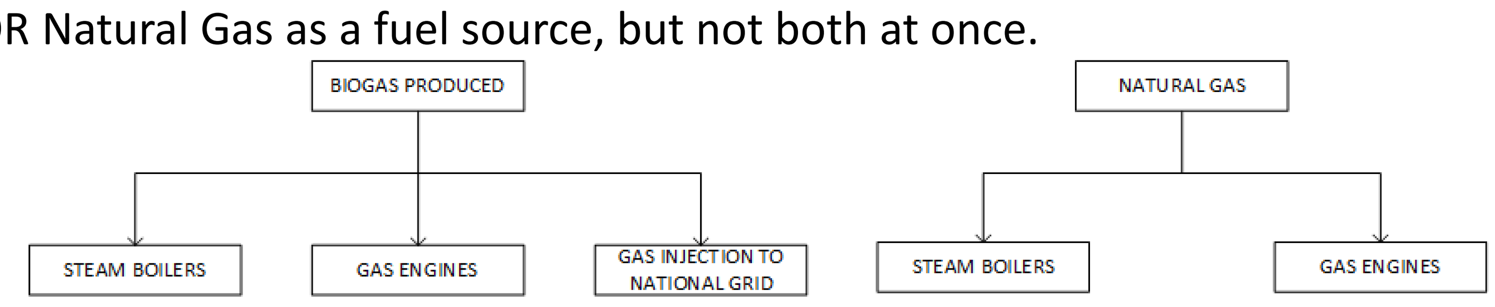

Figure 3 – Gas Distribution on Site

- Adapting the centrifuge model, an improved MILP model for Gas Distribution on site can be written as:

Key:
C_b = Cost of burning Biogas
C_n = Cost of burning Natural Gas
C_I = Cost of injecting biogas
C_f = Cost of flaring biogas

B_t = Biogas Volume
N_t = Natural Gas Volume

z_i = binary variable, to ensure only one gas type is used

$$T_c = \sum_{t=1}^{N_t} (C_b\, B_t\, z_i) + \big(C_n N_t (1 - z_i)\big) + \cdots \quad \text{CHP Engines}$$

$$\sum_{t=1}^{N_t} (C_b\, B_t\, z_i) + \big(C_n N_t (1 - z_i)\big) + \cdots \quad \text{Steam Boilers}$$

$$\sum_{t=1}^{N_t} (C_I\, B_t) + \cdots \quad \text{Grid Injection}$$

$$\sum_{t=1}^{N_t} (C_f\, B_t) \quad \text{Waste Burner}$$

- The optimiser calculates optimal Biogas and Natural Gas distribution based on minimisation of costs. Historic daily plant operation data was used for November 2017 to October 2018. Passing this data to the optimiser allows for Retrospective Optimisation (RO) of the plant.
- The daily Optimised Operational cost calculated and the Actual Operational cost can then be compared, to analyse the plants operational performance over the past year. The % difference in daily Optimised vs Actual cost was plotted [Fig.6]

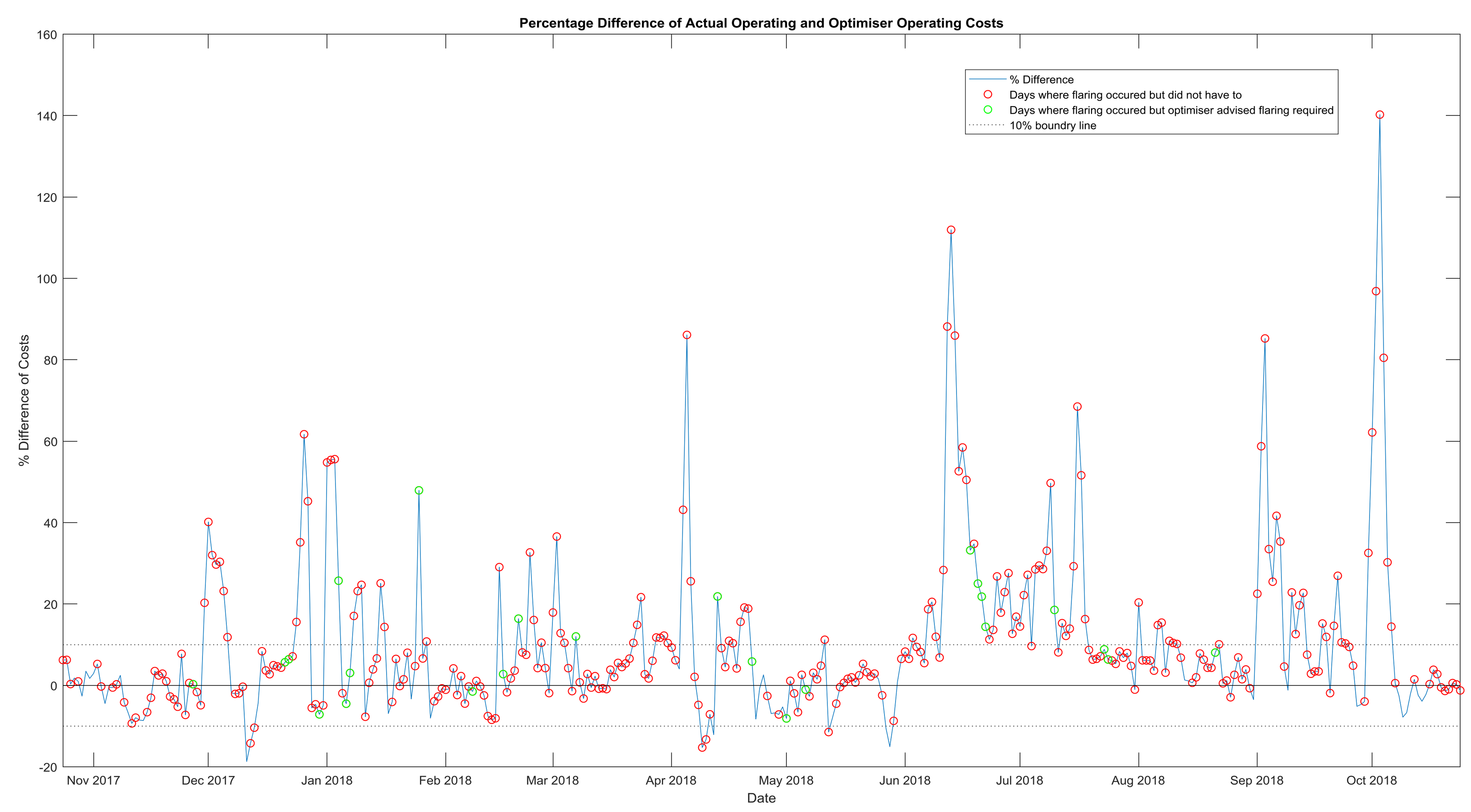

Figure 6 – Percentage Difference in Daily Optimised cost to the Actual Operational cost

Discussion and Future Work

Comparing RO and actual costs [Fig.6] shows that there is potential for plant savings with an improved operational strategy and improved plant robustness.

Currently, the Biogas Optimiser does not include increased electricity import costs associated with lower CHP Engine utilisation. It also does not account for any plant downtime, such as maintenance or equipment malfunctions. The Biogas Model does, however, self validate parameters against historic plant operations.

The next stages of the project will include:

- Create a model of the Anaerobic Digesters to predict Biogas Production based on feed rate and temperature
- Modify Biogas Optimiser to be 'modular', such that the operator can select how many of each unit (engine, boiler, etc.) are available and thus can make better decisions

References
1. Cummings, T., Adamson, R., Sugden, A., Willis, M. J. (2017), Retrospective and predictive optimal scheduling of nitrogen liquefier units and the effect of renewable generation - *Applied Energy 208* 158–170

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