Watermatex 2015
9th IWA Symposium on Systems Analysis and Integrated Assessment
14-17 June 2015, Gold Coast, Australia

The Impact of Energy Tariffs on the Operation of Water Resource Recovery Facilities

Rieger, L.*, Aymerich, I., Rosso, D.***, Sobhani, R.***, Schraa, O.*, Rodriguez-Roda, I.**, and Corominas, L.****

* inCTRL Solutions Inc., Oakville ON, L6J 2K5, Canada.
** Catalan Institute for Water Research (ICRA), Emili Grahit Street, 101, H2O Building, Girona, Catalunya, Spain.
*** Department of Civil and Environmental Engineering, University of California, Irvine, CA 92697-2175, USA.

Keywords: process control, energy costs, energy tariffs

Summary of key findings

The paper presents a case study demonstrating the importance of taking energy tariff structures and equipment efficiency curves into account when comparing control solutions in water resource recovery facilities (WRRF). In most energy studies, the energy consumption is multiplied by an average energy price. However, energy costs significantly depend on the energy tariff structure applied (Aymerich et al., 2015). In order to demonstrate the impact of energy tariffs and equipment efficiencies, a case study comparing two ammonia-based aeration controllers is presented. An energy tariff from Southern California Edison (SCE) is used in the case study and coupled with a WRRF model to highlight the significant impact of time-of-use and peak power demand charges. The results show a reduction potential for energy of over 20% for both ammonia controllers with a slightly better performance of the on-off ammonia controller in terms of effluent total nitrogen and energy consumption. However, after applying the energy tariff from SCE, the cost savings are reduced to 3% for the on-off controller and 10% for the PID controller.

Background and relevance

WRRFs are oftentimes a community's single largest energy consumer with aeration being the biggest consumer within the facility (between 50 and 70% of total electricity consumption). Process control has been successfully applied to minimize energy consumption while meeting effluent permits. Ammonia-based aeration control has been proven to be the most energy and water quality effective control solution as shown in numerous studies (Rieger et al., 2012, Amand et al., 2013). However, reducing energy does not necessary mean reducing costs (Aymerich et al., 2015), and hence, proper cost models are required to take a more qualified decision about the best strategy to apply. When the energy tariff is not taken into account in the controller design, one potential consequence is that energy consumption is lowered but the energy bill is increased. So far, in most energy and control studies the energy consumption is multiplied by an average energy price (inter alia, Ekman et al., 2006, Stare et al., 2007) or a sum of weighted factors (Gernaey et al., 2014). However, operating costs are continually increasing (Olsson, 2012) and this necessitates a proper energy cost evaluation when comparing control strategies. Moreover, predicting the energy consumption under dynamic conditions is similarly important, as control actions leading to equipment operation in inefficient ranges will unnecessarily increase energy consumption. In the presented case study we will demonstrate these two behaviours by introducing a detailed energy cost model based on the SCE energy tariff and evaluating three different aeration controllers based on DO and total ammonia (NH_x) measurements.

Results

Example plant. In the presented case study we use the plant layout as defined by the IWA BSM group (Gernaey et al., 2014) which was developed to compare control strategies. The plant layout is based on the BSM1_LT layout and modelled in SIMBA# (ifak e. V., Germany). The original BSM blower and pump models were substituted with more detailed ones (SIMBA#, 2014). The models include variable efficiency curves, capacity bounds, and parameters to mimic different specific types of equipment. The energy efficiency models for pumping, mixing and aeration are adjusted based on Mueller et al., 1999. As only the energy consumption for aeration and pumping (return activated sludge internal recycle, wastage) was modelled, an additional 50% of energy was added to account for the extra energy (e.g. for influent pumping, heating, lighting) that a WRRF of that magnitude would consume.

Control strategies. A classic feedback dissolved oxygen (DO) controller is compared with two ammonia-based aeration controllers. The DO-PI control (Base Case) manipulates the total airflow to maintain a set-point of 2 g DO/m^3. The NH_x-ONOFF activates or inactivates the DO-PI controller after comparing the ammonia (NH_x) concentration in the last aerobic reactor with the desired NH_x set-point: activate (DO set-point of 2.5 g DO/m^3) when the ammonium concentration is above 3.5 g NH_x-N/m^3 and inactivate when it is lower than 2.5 g NH_x-N/m^3. The NH_x-PID control adjusts the DO set-point of the DO-PI with a master PID controller to maintain a set-point of 3 g NH_x-N/m^3 in the last aerobic reactor.

Energy cost model. The energy tariff model is based on the SCE price structure for large industrial customers (TOU-8, 2014). The implementation of the tariff has been done according to the principles described in Aymerich et al. (2015). The modelled energy tariff consists of the following three general billing terms: i) Energy Usage Charges, ii) Peak Power Demand Charges, and iii) Customer Charges. The energy pricing structure applied to the Energy Usage and Peak Power Demand Charges is based on a Time-Of-Use (TOU) tariff structure with three summer periods and two winter periods (**Table 1**). For further information see TOU-8, 2014.

Table 1 Rates charged by SCE for its industrial clients (option B) at voltage from 2 kV to 50 kV (TOU-8, 2014).

		Delivery Service	Generation
Customer Charge (USD/Meter/Month)		312.31	
Energy Charge (USD/kWh/Month)			
Summer	On-peak	0.024	0.124
	Mid-peak	0.024	0.064
	Off-peak	0.024	0.038
Winter	Mid-peak	0.024	0.064
	Off-peak	0.024	0.038
	Peak Demand Charge (USD/kW/Meter/Month)		
	Facilities Related	14.32	
	Time Related		
Summer	On-peak	0	26.19
	Mid-peak	0	7.22
	Off-peak	0	0
Winter	Mid-peak	0	0
	Off-peak	0	0

Full Cost Model versus Constant Energy Price. For the Base Case using a DO-PI aeration control strategy we observe that a large variation in costs is obtained with the full energy cost model when comparing winter and summer months (**Figure 1**). When applying a constant energy price, the results are relatively constant between $32,000 and $40,000 / month due to a balanced energy consumption throughout the year (**Figure 1**). For the SCE energy tariff, the Peak Power Demand Charges contribute the most to the total energy costs, followed by the Energy Usage Charges, and finally the Customer Charges. Comparing winter and summer months, the Peak Power Demand Charges double during the summer months, leading to significant increases in the total energy costs.

Comparison of Control Strategies. The two ammonia-based aeration control strategies show a significant potential to save energy (**Figure 2**) and at the same time reduce total nitrogen discharge. The NH_x-ONOFF and NH_x-ONOFF controllers reduce energy consumption by 22.4% and 21.5% compared to the DO-PI (Base Case), respectively. In terms of total nitrogen removal, the NH_x-ONOFF reduces the TN discharge by 43.5% and the NH_x-PID by 42.4%. Although the difference is minor, a plant might decide to use the ammonia on-off controller due to its slightly better performance.

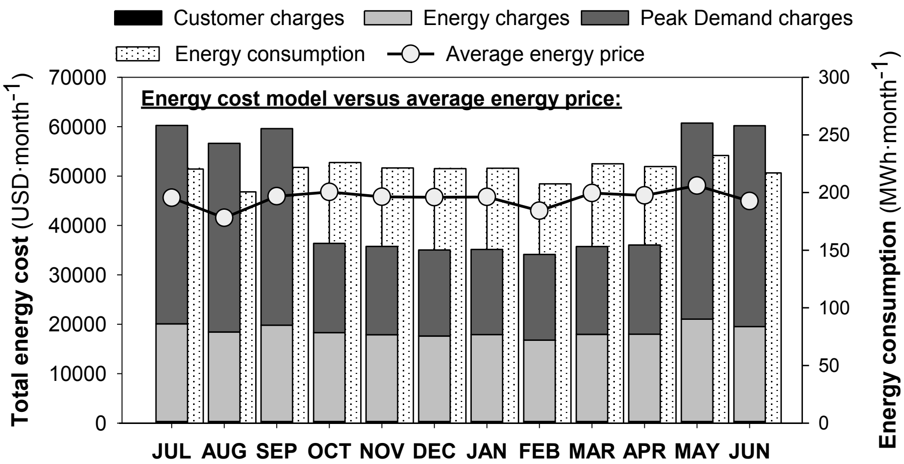

Figure 1 Evaluation of the energy costs by using: i) the Real energy cost model (bar plot) and ii) an average energy price of 0.207 $/kWh (line plot). The total energy consumption is given on the right axis.

Applying a cost model with a constant energy price, the relative cost savings potential would be the same as for the energy reduction. If the full cost model is applied, the results are substantially different. The energy costs for the NH_x-ONOFF are now the highest, and only slightly less than in the DO-PI. This is due to the much higher Peak Power Demand Charges when the blowers are switched back on after an off period with a high power demand during a relatively short period of time. As a result of using the cost model, the percent savings for the total cost drops to 10% for the NH_x-PID controller and to around 3% for the NH_x-ONOFF.

The difference between the reduction potentials for air flow and energy consumption shows the impact of the blower efficiency for the two ammonia-based aeration controllers (**Figure 2**). A constant efficiency throughout the working range would result in exactly the same reduction potential. However, the better performance in terms of air flow requirements is counterbalanced by the PID controller (NH_x-PID), running more often in a lower air flow range with a reduced efficiency.

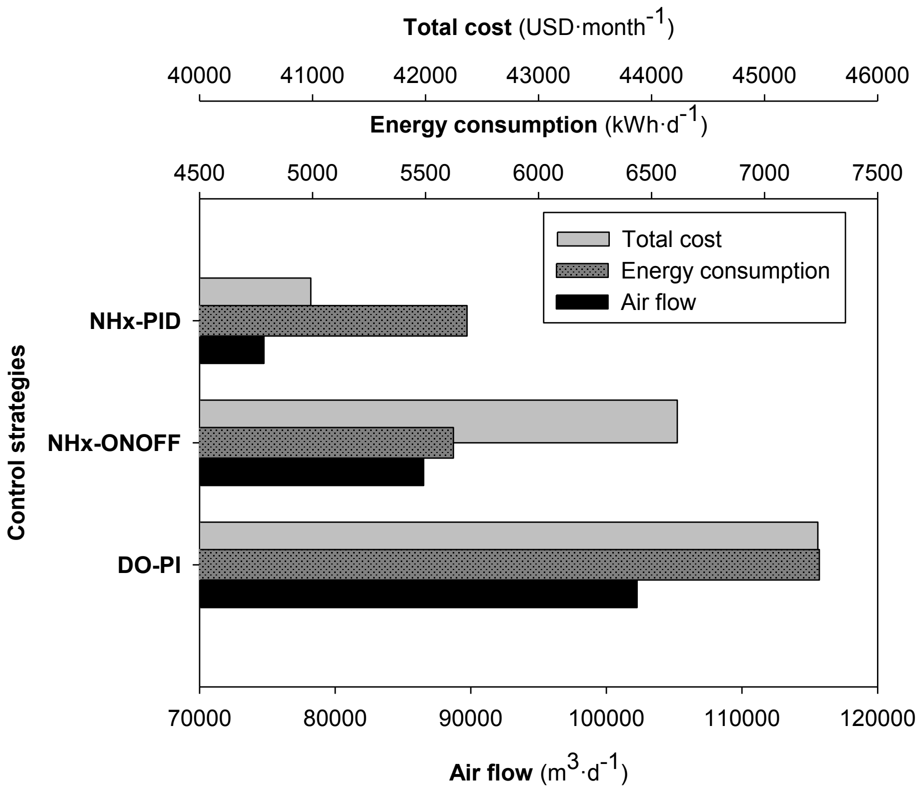

Figure 2 Comparison of (i) Total costs, (ii) Energy Consumption, and (iii) Air flow for the three Aeration control strategies.

Discussion

The presented case study demonstrated the importance of taking energy tariff structures and equipment efficiency curves into account when comparing control solutions. The comparison of three aeration control strategies showed that ignoring the above may lead to biased conclusions.

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