Energy efficiency in the European water industry: learning from best practices

J. Frijns, R. Middleton, C. Uijterlinde and G. Wheale

ABSTRACT

Energy costs and climate change challenges the water industry to improve their energy efficiency. The number of examples of energy measures in water production and treatment is growing rapidly. In this paper, best practices of energy efficiency from the European water industry are presented with the objective of learning from each other. The best practices are collected within the framework of the Global Water Research Coalition’s attempt to devise a global compendium ‘Best practices in the energy efficient design and operation of water industry assets’. The case studies in the compendium show significant energy savings in all parts of the water cycle. Examples with potential include the improved operational set up of pumping design, on line aeration control, and energy-efficient bubble aerators and sludge belt thickeners. Next to optimising energy efficiency across the water cycle, there are also opportunities for energy generation. Promising practices include biogas production from sludge (co)digestion and hydraulic energy generation from micro-turbines.

Key words | best practices, energy efficiency, Europe, (waste)water

INTRODUCTION

Water utilities face the challenge of becoming more energy efficient. After manpower, energy is the highest operating cost item for most water and wastewater companies. High energy consumption will affect the water industry worldwide and is inextricably linked to the issue of climate change. Climate change confronts the water sector with the need to optimise energy use and limit greenhouse gas emissions from their operations (Smith et al. 2009). By doing so, water utilities can contribute to the striving by European and national governments for substantial energy reductions in the coming years of up to 20%.

In the European water industry, building and managing its infrastructure in a cost-effective, energy-efficient manner is nowadays seen as an important responsibility. The number of examples of energy measures in water production and treatment is growing rapidly. In this paper, best practices of energy efficiency from the European water industry are presented with the objective to learn from each other. Transferring best practice is a good means of knowledge brokerage through which organisations could benefit from each other (Burt 2004). The present paper showcases 25 energy-efficiency initiatives which were collected as case studies from European water utilities, i.e. from Belgium, Denmark, France, Germany, Hungary, The Netherlands, Norway, Spain, and Switzerland. The European best practices are collected within the framework of the effort of the Global Water Research Coalition (GWRC) to devise a global compendium ‘Best practices in the energy-efficient design and operation of water industry assets’. Next to an overview of case studies and examples of energy-saving projects, the compendium presents fact sheets and technical guidance on the subject areas with greatest potential (UKWIR & GWRC 2010).

Objective

The purpose of this GWRC project was to document current international best practices in energy efficiency and technologies for the design and operation of water industry assets.
Developments and future opportunities were identified that delivered:

- incremental improvements in energy efficiency through optimisation of existing assets and operations; the ‘low hanging fruit’;
- more substantial improvements in energy efficiency from the adoption of novel (but proven at full scale) technologies.

The benefits of the compendium will be increased comprehensive guidance on energy efficiency, reduced energy use and cost and a reduction in carbon footprint. The project was actively supported by the GWRC members worldwide as represented by the four Continental Coordinators in Australasia (Australia and Singapore), Europe, South Africa and the USA. Each continental group drafted a report of best practices submitted by individual utilities in their region. This article comprises the findings from the European case studies, excluding the UK practices which were reported separately.

**METHODS**

The project looked at the whole water cycle from abstraction to discharge, covering water treatment and distribution, wastewater conveyance and treatment; water reuse; sludge treatment and disposal, and included water conservation, hydraulic energy recovery and generation from waste and sludge. An initial desk study and literature review focused attention on key areas of the industry with most potential for energy efficiency improvements. A ‘priority short list’ was compiled and discussed with all parties early in the project to focus attention on the parts of the water cycle and technologies thought most likely to yield the greatest energy savings.

The priority shortlist was circulated to the four Continental Coordinators who identified case studies of cost-effective energy reduction projects that validated, conflicted with or extended the initial study conclusions. Following a data collection phase, in which each case study was analysed and written up using a relatively prescriptive methodology and data collection pro-forma, each Continental Coordinator drafted their regional report summarizing the findings from their case studies.

**Accessibility of information**

It was recognised from the outset that the significant amount of information and data in the compendium would need to be presented for ease of reference. This has been facilitated by the water cycle energy-saving matrix (see Table 1). This is a table with the water cycle across the top, and down the left hand column are the various techniques and processes used in the industry. The 25 European case studies are plotted in the matrix.

The matrix allows the user to pinpoint their interest and see quickly what technologies and examples are available. The compendium is a complete electronic document and the user can click on a process in the matrix to go straight to the relevant fact sheet. The process and its major issues are described, the technology is explained and there are estimates of what savings can be made with relevant case study references. If the user clicks on a case study in the matrix, the links go straight to the case study document. Information is presented in a standard format including the location and any regulatory background, starting and end situations, changes made, savings, costs, operation and other impacts. The user can therefore quickly find details of the technology and examples of energy efficiency projects in any area of interest, which may be on the other side of the world or in their own backyard. It is hoped that this will stimulate further activity in energy saving and particularly help those utilities without access to research or advanced engineering facilities.

**RESULTS AND DISCUSSION**

**Energy options**

There are numerous options for energy measures in the water sector ranging from water conservation and process efficiency improvements to new technologies and redesign of water systems. Examples of energy measures that are available for actual implementation (i.e. proven technologies) identified in this project include:

- leakage reduction and water conservation;
- water distribution system: optimised gravity flow, demand modelling;
- energy-efficient water treatment, e.g. low pressure ultraviolet (UV), high yield membranes;
• pumps: efficiency improvements, e.g. duty point and duty rate selection, variable speed drives, inter stage pumping, reduced returned activated sludge pumping;
• sewerage: infiltration and inflow reduction, real time control;
• aeration in wastewater treatment plant (WWTP): energy-efficient bubble aerators, on line aeration control;
• nutrient removal: ensuring correct sludge age, ammonia derived dissolved oxygen control, separate treatment of reject sludge water for N-removal;
• mixers: high yield equipment, combined mixing with pumping and/or aeration;
• UV treatment: enhanced inflow quality, dosing rate variation with effluent quality;
• sludge thickening: low energy equipment (e.g. belts);
• maximised digestion by increased primary sludge feed, sludge pretreatment, high yield gas motor and/or operational improvement (mixing, temperature);
• biogas combined heat and power: process optimisation, co-digestion and enhanced biogas conversion and use (e.g. green gas);
• sludge end treatment: maximum dewatering to reduce drying energy demand;
• hydrogeneration (micro-turbines);
• heat recovery from wastewater at households or from the sewer system;
• energy measures at buildings, and solar energy and wind turbines installed at premises.

Table 1 | Water cycle energy-saving matrix

<table>
<thead>
<tr>
<th>Raw water</th>
<th>Treatment</th>
<th>Distribution</th>
<th>Sewerage</th>
<th>Treatment</th>
<th>Disposal</th>
<th>Re-use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current energy usage estimate (%)</td>
<td>25</td>
<td>10</td>
<td>65</td>
<td>20</td>
<td>60</td>
<td>15</td>
</tr>
</tbody>
</table>

Demand Management

Conservation
Leakage reduction

Pumping
Optimise gravity flow
Transfer pumps
Catchment transfer
Aquifer recharge

Treatment
Screens/preliminary
Sedimentation
Aeration/mixing
Filtration
Intermediate pumping
Filtration GAC
Protection membrane
Desalination membrane/thermal
Disinfection/UV
Ozonation
Tertiary treatment
Optimise operations/process

Sludge
Sludge thickening
Sludge digestion
Sludge drying
Disposal to land

Building services

Generation
Mini hydro-turbines
Heat pumps
Wind turbines
Biogas/cogeneration
Incineration

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Demand Management
Conservation
Leakage reduction

Pumping
Optimise gravity flow
Transfer pumps T1
Transfer pumps K3, T2
Aquifer recharge

Treatment
Screens/preliminary S3, S4
Aeration/mixing S6, S7
Filtration K4, K5
Protection membrane S2
Desalination membrane/thermal
Disinfection/UV K1
Ozonation K4
Tertiary treatment V3

Sludge
Sludge thickening S8, S9
Sludge digestion S1, SE2, E1
Sludge drying SE1
Disposal to land

Building services

Generation
Mini hydro-turbines V2
Heat pumps V1
Wind turbines
Biogas/cogeneration S5, V4, E2, E3
Incineration

Incineration

*Refers to European case study code, see Table 2.
GAC: granulated activated carbon.
There are certainly additional energy options for the water industry one could think of. However, the emphasis of the project and this paper is on the actual implementation of energy efficiency measures by water utility companies with the objective of learning from real-life practices. The next paragraph gives an outline of selected cases.

### Energy gains

Table 2 gives the main characteristics and the energy efficiency savings of the selected case studies.

The case studies show significant energy savings and energy generation in all parts of the water cycle. Energy savings are achieved through various measures such as:

- **Reduced energy use for UV-treatment** due to enhanced coagulation (K1, 7.7 million kWh/yr (35%));
- **Hydraulic connection of water pumping stations** (K2, 700,000 kWh/yr (5%));
- **Variable frequency drives at a water collection well** (K3, 100,000 kWh/yr (15–20%));
- **Reduction of energy consumption by retrofitting the water treatment into ozonisation combined with two-stage GAC filtration** (K4, 3 million kWh/yr);
- **Energy saving from a coagulation optimisation procedure** (K5, 60,000 kWh/yr (5–10%));
- **Optimisation of MBR operation** (S2, 0.1–0.3 kWh/m³);
- **Increase of sludge production with AB-process** (S3, 20% lower energy demand and 20% more biogas);
- **Advanced primary settling** (S4, 200,000 kWh/yr);
- **Co-digestion external organic wastes** (S5, 60 million m³/yr biogas generated);
- **Sludge age depending on temperature** (S6, 10–15%);
- **Energy efficient plate aerators** (S7, 25%);
- **Belt thickening instead of decanters** (S8, 230,000 kWh/yr (60%));
- **Energy production out of RPM reduction** (S9, 25,000–45,000 kWh/yr);
- **Energy savings using sludge combustion exhaust gases for thermal drying** (SE1, From 1,000–2,000 to 200–250 kWh/ton ds (90%));
- **Energy and economic savings using biogas for electricity and heat generation** (SE2, 19.2 million kWh/yr (25%));
- **Micro-turbines on WWTP effluent** (V1, 6 million kWh/yr generated);
- **Micro-turbines on drinking water treatment plant** (V2, 4.5 million kWh/yr generated);
- **Energy optimisation with advanced online process control** (V3, 1.3 million kWh/yr (16%));
- **Energy recovery from sludge and waste (co-digestion)** (V4, 10 million kWh/yr);
- **Biogas production from sludge digestion** (E1, 3.3 million kWh/yr generated (80% of electricity need));
- **Green gas delivery to the grid** (E2, 25% of biogas converted to biomethane);
- **Optimised use of sewage gas with microgasturbines** (E3, Depends);
- **Pigging the head loss of raw water pipe** (T1, 3 bar lower head loss);
- **Variable frequency drivers at distribution pumps** (T2, 15% lower energy consumption).

MBR: membrane bioreactor; RPM: revolutions per minute.
gains result from operational optimisation and technology improvements.

**Operational energy optimisation**

Several case studies show that substantial energy efficiency gains can be achieved by operational optimisation measures. For example, at water production site Andijk (case study code K1 The Netherlands), the energy consumption of UV-treatment was reduced from 0.60 to 0.38 kWh/m³ by decreasing the dissolved organic carbon level. This was achieved by changing the pH-correction after coagulation. The energy gain of this enhanced coagulation before the UV/H₂O₂-treatment is about 35%. This resembles a total energy gain of 7.7 million kWh/yr.

In wastewater treatment, aeration typically consumes 60% of the energy budget, and optimisation of aeration is thus key (Heinonen et al. 2003). Simple gains of up to 20% are possible on some aerobic wastewater systems by aligning control parameters with the discharge consent (S6 The Netherlands and V3 Denmark). At the Avedore biological wastewater treatment plant in Denmark (V3), installation of advanced online process control (based on measurement of ammonia, nitrate and oxygen) resulted in a 16% decreased energy consumption (average of 6 years). Its specific energy use is now reduced to 0.28 kWh/m³.

**Adoption of energy-efficient technology**

Case studies in drinking water production and distribution, wastewater treatment and sludge treatment show the adoption of energy-efficient technology. Substantial gains have been achieved with energy-efficient pumps, plate aerators (S7 The Netherlands) and belt thickening (S8 The Netherlands).

Pumps and pumping represent an area with large potential for energy savings (McVay 2009). Simple gains are possible in some pumping situations where the operational set up has been changed from the design condition. Together with applying variable frequency drives and adopting energy-efficient pumps, gains of between 5 and 30% may be realised in drinking water extraction and distribution (K3 Belgium and T2 Germany).

**Energy generation**

There is high potential for energy recovery and generation from wastewater through chemical energy generation (biogas from organic carbon) and thermal energy recovery (from heat in domestic wastewater) (Frijns et al. 2009). The recovery of chemical energy in wastewater can be maximised by organic carbon concentration for anaerobic conversion to biogas. The increase in primary sludge production reduces the load on aeration blowers and increases digester biogas production (S3 and S4 The Netherlands). The net energy efficiency is thereby increased with sludge digestion and on site combined heat and power.

Also co-digestion with external organic waste (S5 The Netherlands and V4 Hungary) increases the energy generation. Integration of a waste processing unit (food and beverages wastes, restaurants, supermarkets, slaughterhouses, milk industry) and a thermophilic co-digester on the WWTP of Budapest, which already was equipped with a sludge mesophilic digester, resulted in 10 million kWh/yr electricity savings. The WWTP is now heat self-sufficient and produces 70% of its power needs (V4).

Case studies from France (V1 and V2) show the potential of hydraulic energy recovery from micro-turbines.

**Energy hierarchy**

Drawing lessons from the worldwide Compendium as well, Table 3 presents a selection hierarchy based on the energy demands of current processes. As the case studies did not produce sufficient evidence to allow quantitative analysis of the treatment options, Table 3 represents generic hierarchies only based on experience in typical circumstances as a guideline towards process and plant selection. Obviously this hierarchy is not conclusive as the actual energy demand of the different processes is affected by operational conditions, process setup, treatment capacities, etc.

‘Drinking water only’ companies have limited opportunities for net energy gains. In part, the lack of opportunities reflects the low energy usage for treatment compared with the dominance of pumping usage.

Energy usage in wastewater treatment processes is much more variable. A trickling or deep bed filter process has very low energy requirements and hence minimal opportunity for
significant gains. Other processes, such as activated sludge plants and returned activated sludge pumping, where pollution loadings and standards have direct impact on energy usage, may present opportunities for significant gains. Case studies have reported between 15 and 50% possible gains on aeration energy demand, so, given that some works must be operating close to ideal efficiencies, the average may be as high as 25%. The case studies also show that gains can come from incremental changes, such as matching instruments or controls to consent parameters, as well as more capital intensive exercises.

For thickening sludge, the characteristics of the sludge are the key parameters although, all other things being equal, the energy hierarchy would seem to favour picket fence or drum thickeners over belt thickeners, which are favoured over centrifuges.

### CONCLUSIONS

The European case studies show significant energy savings in all parts of the water cycle. Overall energy efficiency gains of between 5 and 25% seem realistic. Both incremental improvements in energy efficiency through optimisation of existing assets and operations and more substantial improvements in energy efficiency from the adoption of novel technologies can be distinguished. There are two areas with most potential; pumps of most types and functions, and aerobic wastewater treatment systems. Examples with potential include the improved operational set up of pumping design, on line aeration control, and energy-efficient bubble aerators and sludge belt thickeners. Next to optimising energy efficiency across the water cycle, there are also opportunities for energy generation. Promising practices include biogas production from sludge (co-)digestion and hydraulic energy generation from micro-turbines.

It is estimated that most of the viable energy efficiency savings can be achieved in about ten years with the right regulatory framework or corporate will. The remainder of the challenge, beyond 25% efficiency savings, will then be to develop new water cycle concepts and technologies. A balance may also be struck between the energy demand for higher treatment standards and the pollution caused by generating and transmitting that energy. This would call for discharge consent standards, both absolute and varying seasonally, in relation to the end use of the water or the quality of the receiving water.

The compendium contains a collection of best practice case studies and a review of the best technologies for energy efficiency in the international water and wastewater industry. The expectation is that the compendium will be of value to the water industry to guide them towards improving their own ways of working from an energy efficiency perspective. In doing so, the water industry will make a significant contribution to mitigating climate change by reducing its carbon footprint.

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REFERENCES


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