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Hydropower opportunities in the water industry

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ABSTRACT

Water and wastewater treatment processes are energy intensive accounting for around 30 to 80 percent of the industry production cost. Given this background, the water companies agree on the need to identify cost effective and sustainable ways of producing energy to reduce its dependence on fossil fuel for energy generation, reduce its carbon emissions, ensure the security of its power supply and offset the increasingly energy cost. Micro-hydropower, a resource that is readily available at the door step of the water companies has been identified as the solution to a sustainable energy option for the industry. Nonetheless, there are no detailed options in the available literature of hydropower application to the water industry**.** This paper thus gives an overview of hydropower application options available to the water industry (water and wastewater treatment industry.

Keywords: Water Industry, hydropower, Feed-in-tariff

1. Introduction

The need to reduce the cost of energy used in the treatment of water and wastewater has grown as one of the major concern of the water industry over the last few years and it is expected to become more important in the near future. The main reason for this is because the water and wastewater industry is a heavy user of electricity and in the UK, it is the fourth-largest energy-intensive sector, releasing over 4 million tonnes of greenhouse gas emissions (GHG) annually (EA, 2010).These figures are likely to increase in future as a result of the rise in population rate, together with the expansion of industrial activities (Wolfgang,1994), the increasingly stringent water quality coupled with the future need to supplement water supply by treating wastewater for reuse. In water treatment process, most of the energy used is for lifting water from one place to another which can involve pumping water from long distance to the treatment plant and to the distribution reservoir after treatment. In the wastewater treatment, the removal of contaminants are energy intensive ; a typical activated sludge treatment process accounts for about 30 to 80 percent of the total plant electricity demand (Pakenas,1995).

Addressing the problems of energy sustainability in the water and wastewater industry thus requires a thorough review, and research into technologies that are cost effective and sustainable for each location. Take for example; it would be unwise to consider wind power in locations where there is hardly any wind. The industry thus need to harness renewable and non-polluting resources that are at its doorstep .Currently, anaerobic digestion accounts for the industry's main source of renewable energy and represents 90% of UK renewable energy generation sources. However, renewable energy generation such as harnessing energy created by low head , high flow at wastewater treatment facilities and high head, high flow from energy destroyed from pressure reducing valves in water conveyance systems still remain less exploited (Bennett, 2007).,

The highly developed and proven technology of hydropower that is used worldwide to generate renewable energy from flowing water with a hydraulic gradient (Price et al, 1997) is one of the possible sustainable energy solutions for the water industry.

Hydropower currently accounts for around 68% of the world total renewable energy production (Renewable, 2006). All other renewable energy combined provides less than 2% of the global renewable energy production (Renewable, 2006). In the UK alone, it accounts for 1.3% of electricity generation, mainly from large-scale hydro schemes in Scotland (Decc, 2009).

Within the water industries in England, Wales and Northern Ireland, the available literature estimates a small-scale hydropower potential of 17 MW (Salford Civil Engineering Ltd., 1989.Not only is hydropower a continually renewable and proven technology, it is a non-polluting energy resource (Kirk, 1999) and the payback time on capital investment is normally within the lifetime of the equipment (Bahaj et al, 2007).

However, due to the geographical location of the UK water and wastewater industries, not all treatment facilities' will be economically viable for hydropower. This is because for a hydro scheme to be viable, to yield a return of investment, either the head or the flow must be significant (Paish, 2002). A higher head tends to be the most cost-effective as a smaller amount of flow is required to produce the same amount of power. A lower head can still be viable but may require high capital investment and have a longer payback period

The objective of this paper is to give an overview of Hydropower application to the water and wastewater treatment facilities and to reviews hydropower options available to the water industry. The current status and research and development of hydropower in the water industry are also discussed.

2. Hydropower Theory

Energy from falling water can be harnessed to provide electrical power. The theoretical energy from a site depends on the flow of the water and the height of the water fall at the site. In order to estimate the hydropower potential from a site, it is important that the head and the flow of water over a period of time be measured. The theoretical power from a site can be computed from the equation given below:

$$\text{Power} = \rho \times g \times h \times Q \times \varepsilon$$

where P is power in watts (w), ρ is the water density (1000 kg/m^3), g is the acceleration due to gravity (9.81 m^3/s), h is the available net head (m), Q is the discharge flow (m^3/s) and ε is the efficiency.

$$\text{Annual energy (kWh/year)} = P\ (KW) \times CP \times 24\ \text{hrs} \times 365\ \text{days}$$

where CP is the capacity factor, which tells how long the turbine will be in operation, and is expressed as follows:

Capacity factor (%) = Energy generated per year (kWh/year) / P (KW) × 24 hrs × 365 days

3. Classification of hydropower

The classification of small hydropower based on installed capacity is inconsistent throughout the hydropower literature and varies depending on the location (Demirbas, 2005). Hammad et al (1994) and Paish (2002) defined it as a unit with power less than 100 MW, which is the same as the classification of the European Small Hydropower Association (ESHA). While other countries like France set it at 8 MW (ESHA, 1998), the USA at 30 MW (Ramage, 2004) and India at 25 MW (Singal et al, 2008), the UK puts it at less than 5 MW, as shown in table 1.

Micro-hydropower, which is the focus of the present study, is generally defined as having power less than or equal to 100 kW (Hammad et al, 1994; Paish, 2002), although Kirk (1999) set it at less than or equal to 500 MW. However, based on the current literature, this study will adopt the limit of 100 kW as micro-hydropower.

Table 1: Classification of small-scale hydropower

Type	Station capacity	Unit capacity
Micro-hydro	Up to 100 kW	Up to 100 kW
Mini-hydro	101 to 2000 kW	101 to 1000 kW
Small hydro	2001 to 25,000 kW	1001 to 5000 kW

4. Hydropower in Water and Wastewater Treatment Facilities

4.1 Sewage treatment outfall

Instead of discharging treated sewage effluent directly into the receiving water body, it can be diverted through a penstock under pressure into a turbine to generate electricity (Pakenas, 1995). As shown in figure.1 below, the treated effluent passes through a trash rack via an inlet gate into the penstock and down to the turbine, where it strikes the blade and causes the shaft connected to the generator to rotate, thereby converting the rotating shaft into electricity (Saket, 2008). The power generated can be used on site to displace the energy bill of the treatment works or exported to the grid for sale if excess power is produced.

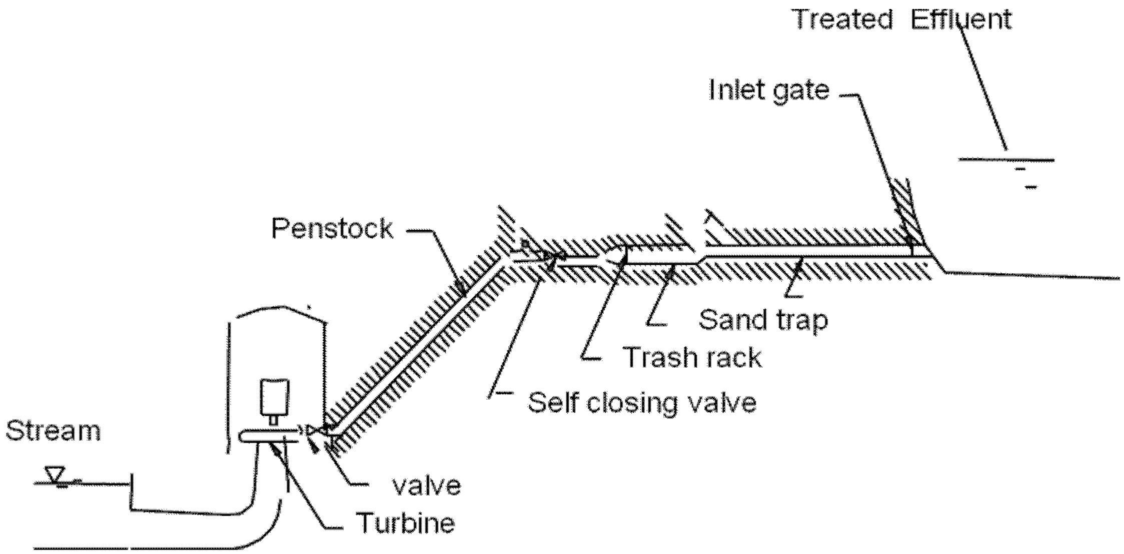

Figure 1: Schematic illustration of the micro-hydropower layout for sewage treatment works' outfall

Environmental effects from large-scale hydro such as the effects on migratory fish passage and the fear of flooding to the environment do not apply when used in water treatment distribution pipe works and wastewater outfalls (Zakkouret al, 2002; Saket, 2008). Hydro in sewage treatment works' outfall can increase the dissolved oxygen concentration in the treated stream (Zakkouret al, 2002). In addition, institutional barriers to hydropower development at other sites do not apply when implemented within the water and wastewater industry (Wallace, 1996).

However, not all wastewater treatment works can take full advantage of this exciting technology because the feasibility of hydropower for any site depends principally on the available net head and the flow regime of the treatment works to generate enough energy to be worth the investment. To optimise a hydropower scheme, either the head or the flow must be significant (Kirk, 1999). Treatment facilities located within hilly terrain, mountains and valleys are likely to produce a significant amount of power at a relatively low cost and with a shorter payback time. This thus gives an advantage to some treatment works due to their geographical location. In the UK, high-head locations are uncommon (Paish, 2002). Although recent studies showed that hydro with a head as low as 1 m can be economically viable (Fuentes, 2004), but mostly for hydro in run-off rivers and particularly when there is some existing civil infrastructure to reduce the civil cost. The cost of investment in hydro can be high but the operation and maintenance costs are low. As a general rule of thumb the capital cost of small-scale hydro is in the region of £3000–£6000 per installed capacity. The investment cost decreases as the installation capacity increases (Kirk, 1999).

Further, it is possible to match the capacity factor of a turbine with the flow profile and energy consumption at a sewage treatment works (Zakkouret al, 2002; Saket, 2008). High and low flows equate to high and low energy usage in the treatment works and thus the turbine will produce power to meet the base and peak flows. This can be achieved by selecting a turbine capable of working under variable flow conditions. Most turbines can work at a certain percentage below and above their rated flow within certain efficiency; notable among them is the impulse turbine. A variable flow turbine will ensure a constant supply of electricity all year round. Flows into a sewage works are diurnal; a turbine designed for a high flow will remain idle during dry weather periods and a turbine designed for dry weather flow will run throughout the year. If a system depends fully on hydropower for power generation, the design flow should be flow that is available 95% of the time.(Harvey ,2006)

Turbines could be also incorporated into wastewater treatment process streams. However, a proper study of the hydraulics would be required to ensure that the turbine installed does not cause a network blockage, which could lead to consent failure. A reaction turbine or, alternatively, Pump as turbine(PAT) could be located at the exit flow from pressurised gravity filtration systems such as tertiary sand filters (TSF) to recover energy. A head of around 6 m exists at the exit flow of most TSF and it is possible to generate around 19 kW, which could displace the cost of pumping the water into the filter.

Whilst the application of hydro schemes to water treatment facilities will make a significant contribution to the use of renewable energy sources and reduce GHG emissions, a hydro scheme in STW outfall could only be viable if it qualifies for government incentives. Currently, in the UK, hydro schemes implemented on sewage treatment works' hydraulic head are not entitled to a Renewable Obligation Certificate (ROC). This means that unless the STW has a high flow to produce the same power as a high-head site, the scheme will not be viable. A typical flow rate for a wastewater treatment site treating a wastewater from a population equivalent of 80,000 is around 2 m^3/s and for such a scheme to be viable, a head of at least 5 m may be needed. However, such a head is hardly available in STW unless using an STW outfall that is geographically favoured. This thus show that STW located in south west of the UK may not be economically viable.

4.2 .Compensation flow from reservoirs

Water companies abstracting raw water for treatment from impounded reservoirs and run-off rivers are required by the UK law to release a certain amount of flow into the river course, termed "residual flow" or "compensation flow", to sustain the water quality and protect the river ecology (Wallace, 1996; Arceman et al, 2006). The magnitude of the compensation flow is normally set by the Environmental Agency and can vary between the 90th and 95th percentiles' flow of the mean daily flow duration depending on the quantity abstracted. The 95th percentile is approximately the dry weather flow and must be maintained in the river course at all times.

If water is delivered directly from the reservoir to the treatment works, arrangements are usually made to maintain the compensation flow in the river downstream. This may involve creating an additional outlet from the reservoir to redirect the flow downstream to meet the residual flow requirement. If either the redirected flow or the head is significant, a turbine could be installed at the outlet to harness the energy. The compensation flow of the 90th or 95th percentile may be small for hydro-power generation compared with the amount abstracted to the treatment work, but it has the advantage of being constant, which means that a turbine installed will operate at its peak efficiency at all times, thus providing a consistent electricity supply. Although, residual flows from reservoirs can be a reliable source of energy, it however depends on the amount abstracted to the treatment works and the reservoir terrain. And since compensation flow rates are normally small compared with the amount abstracted; the head of the flow would have to be significant for the scheme to be viable.

During the winter, overtopping and released flow often constitute the main sources of the compensation flow from reservoir, and during the summer, the spill flow only contributes to the compensation flow. In summer, and in low head locations, it is possible to exploit the high spill flow. However, it may not be economical to do considering the unpredictable seasonal durations

4.3. Pressure reducing valves

A typical water treatment process normally begins with raw water abstraction by gravity from high pressure to low pressure, or vice versa, and by pumping where the topography poses a limitation to the gravity flow. Similarly, treated water gravitates or is pumped to reservoirs before distribution to meet demand. In either case, the pressure must be reduced to meet the downstream prescribed value, to prevent loss of water through leakages and bursts pipe within the system.

An approach often used to control pressure in water distribution networks is to install pressure reducing valves (PRV) at critical points within the network to regulate the pressure (Wallace, 1996; Williams et al., 1998) or pressure breaking tanks to break pressure and return the water to atmospheric pressure before onward transmission. PRV works by opening and closing their entries to allow the flow of water to meet the required pressure. PRV can function manually using attached levers, or automatically by connecting them to pressure measuring instruments. Two types of valve configuration are used: spring-loaded and diaphragm-actuated valves (Dasgupta et al., 2002).The former is mostly used for low flow rates and the latter for higher flow rates.

During the process of pressure control in water distribution systems, energy is dissipated. Around 85% of the energy wasted can be recovered by replacing the PRV with a turbine (Woodcock, 1981) or installing the turbine in parallel with the PRV (Wallace, 1996). However, when they are installed in parallel, measures are put in place to allow water to bypass the generator if the turbine shuts down and to prevent damage to the network and plumbing fixtures.

Two types of turbines can be used in the recovery of energy from water distribution networks: Pelton (Impulse) and Francis (reaction) turbines. The choice of turbine for a scheme although is driven by the head and flow range of the scheme (Harvey, 2006) other factors such as rotational speed, runaway speed and cavitation limit are also taken into consideration. In the water distribution network, the scheme mode of flow discharge is also considered, and for schemes discharging at atmospheric pressure, the Pelton turbine is used (Wallace, 1996) while Francis turbines are more suited for pressured flow systems. However, the final choice of turbine depends on the cost benefit analysis of the potential turbines, taking into consideration the annual energy production and performance requirements.

Although, there has been recent applications of pump as a turbine (PAT) to recover energy in water distribution networks, their applications however depends on a trade-off between cost and energy production. The performance of a PAT is difficult to predict accurately, and the fact that they lack a turbine characteristics curve makes it difficult to select the correct pump for a scheme (Williams, et al., 1998). Moreover, the PAT have poor part-flow efficiency making them unsuitable for variable flow systems. For schemes where flows and heads are constant and where significant savings in capital cost is required, it might be worth trying PAT.

Energy recovery turbines can also be used wherever a sufficient pressure differential exists in water and wastewater treatment processes. They can be installed at the exit in closed pipes in pressurised filtration processes, for example in rapid gravity filters used in water treatment (Wallace, 1996) and in tertiary sand filters used to reduce Biochemical oxygen demand(BOD) and suspended solids in waste water treatment systems. Industrial processes, where turbines have been used to recover energy, include: cryogenic systems, petrochemical refinery processes and seawater desalination (Antwerpen et al., 2005).

Other applications for turbine as PRV include, regulating pressure and recovering energy from a cooling spray chamber (Ferguson et al., 1984) and using it in underground air cooling systems in mines (Ramsden et al., 1985). A more recent application was used to recover 25% of wasted energy in bio-gas scrubbing processes (Bansal et al., 2010), an area that appears to be less exploited in the wastewater industry. Irrespective of the type of electro-chemical technology used it is fundamentally important that the proceeds from the energy produced be maximised and the capital cost of the project and the consequent discount rates by minimised.

5. Low-Head Hydropower

“Low-head” hydro is the term often used for a hydro scheme with a head between 5 and 20 m and “ultra-low head” for a scheme with less than 3 m (Fraenkel et al, 1991). A low-head hydro scheme requires a large passage/opening to accommodate a high volume of flow, making low-head turbines inevitably large in size and expensive (Singal et al, 2008), consequently creating a number of engineering challenges.

In addition, low-head schemes suffer from a lot of flow fluctuation due to the variation in headwater and tail water levels. This variation can mean that a head of 3 m is reduced to 1 m, thus reducing the system reliability and power output (MWH, 2004).

Low-head sites tend to be more common in run-off-river hydro schemes (Furukawa et al, 2009) but can also be available in wastewater treatment outfalls. In the flat south east of England, the majority of the hydro schemes have a head less than 3 m (MWH, 2004).

For low-head sites, the conventional procedure is to select and install reaction turbines such as a Kaplan turbine, either as a vertical-axis unit, a right-angle drive or a bulb turbine (Furukawa et al, 2009) or an open-flume Francis turbine with an adjustable vane, as shown in table 2. Although these turbines are technically efficient, they are prohibitively expensive for smaller schemes.

Table 2: Low-head turbine performance characteristics -Singal et al, 2008

Turbine type	Rated head Hr (m)_	Capacity (MW)
Vertical fixed propeller	2–20	0.25–15 and above
Vertical Kaplan (adjustable blade propeller)	2–20	1–15 and above
Vertical Francis	8–20	0.25–15
Horizontal Francis	8–20 and above	0.25–2
Tubular (with adjustable blades and fixed gates)	2–18	0.25–15
Tubular (fixed blade runner with wicket gates)	2–18	0.25–15
Bulb	2–20	1–15
Rim	2–9	1–8
Right-angle drive propeller	2–18	0.25–2
Open	2–11	0.25–2
Closed flume	2–20	0.25–3
Cross flow	6–20	0.25–2

Although the past couple of centuries have seen large-scale development in high-head turbines, this is not the case for low-head turbines. The two main reasons for this are that conventional turbines are expensive and hence the cost of installing a low-head turbine is often comparable with a large-scale hydro scheme (Kirk, 1999), and also low-head turbines are thought to have negative effects on the ecology of the river. However, in recent years, there has been a shift in research towards developing low-head hydropower. This is because the majority of the available hydropower resources are low head and it is believed that they will play a small but significant role in greenhouse gas emission reduction (EA, 2010). The current unexploited low-head hydropower potential in the UK is estimated as 600–1000 MW (Goring , 2000), which is mainly hydro installed on "run-off rivers". In the water and wastewater industry, it is thought to be significant (EA, 2010).

One of the identified factors militating against the uptake of micro-hydropower application within the industry is a lack of reliable technology options to harness the low heads that exist within treatment plants (EA, 2010). The majority of wastewater treatment plants in the UK were built on a flat landscape to take advantage of the gravitational flow of sewage into the treatment works. The low-head differential therefore makes high-head hydropower application technically unfeasible. The option is thus a compact ultra-low-head turbine running at a medium speed, which can be located in the discharge pit, submerged or located prior to the exit flow from the treatment works. Such a turbine should be able to utilise the existing civil structures and be environmentally friendly, cost-effective, durable, a high-load factor installation and efficient as a conventional turbine. There are a few different options for low-head turbines that can be retrofitted or installed into water and wastewater facilities. At present, at least six types of water turbine can be used based on research studies, manufacturer literature and case histories. Some of these turbines are similar and operate with the same concept as conventional turbines but are modified to take many economic and engineering factors into consideration. They include: Archimedes screw turbines, pit turbines, open-flume turbines, watermills, tube turbines and Siphonic turbines. Each type operates over a limited range of head and flow.

6. Conclusion

Hydropower is a proven and generally predictable source of renewable energy and is one of the few that is not intermittent. Although the UK water industry currently exploit other renewable energy sources, there exist varied opportunities to exploit hydropower resources, for micro- hydro development.

Apart from noises from the turbine powerhouse which can be minimised by adequate acoustic insulation, other detrimental environmental effects often associated with hydro schemes, such as the effects on migratory fish passage and the fear of flooding the environment do not apply when implemented and operated within the water industry. The institutional framework often required in other hydro projects such as abstraction licence and flood defence approval requirements is not needed. The viability of investment in hydropower by the water industry depends on the availability of incentives from the government.

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