Energy Conversion and Management 163 (2018) 304–313

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

A novel energy assessment of urban wastewater treatment plants

S. Di Fraia[a,*], N. Massarotti[a], L. Vanoli[a,b]

[a] Dipartimento di Ingegneria, Universitá degli Studi di Napoli "Parthenope", Centro Direzionale, Napoli, Italy
[b] Dipartimento di Ingegneria Civile e Meccanica, Universitá degli Studi di Cassino e del Lazio Meridionale, Cassino, Italy

ARTICLE INFO

Keywords:
Energy efficiency
Energy audit
Indicators
Energy classes

ABSTRACT

Wastewater treatment is a high energy consuming process, and its energy demand is considerably increasing due to the introduction of more restrictive standards on the quality of water effluents, that require advanced technologies for pollutant removal. Energy audits are carried out in order to improve energy efficiency of wastewater treatment plants, by introducing some measures, such as adjustments of the treatment scheme, or optimization of existing operational units. At the same time, energy recovery from wastewater treatment and its by-products is being implemented in order to reduce economic costs and environmental impact of the process. In order to assess the benefits resulting from implementation of these interventions, procedures for evaluation of energy performance of wastewater treatment plants are being developed.

In this work, a novel method is proposed for assessing energy performance of wastewater treatment plants by coupling simple energy performance indicators with specific pollution removal efficiencies. This procedure is applied to a large database of wastewater treatment plants, in order to define some classes of energy performance depending on removal efficiency. The method is also used to analyse some Italian plants, representative of different design and management conditions. As a result, only 8.2% of around 300 plants presents the highest class of performance, considering the energy consumption related to the organic matter removal.

1. Introduction

The aim of WasteWater Treatment Plants (WWTPs) is wastewater purification for water pollution control. Most WWTPs operating today have been designed and built without accounting for energy demand, since energy costs were not a major concern [1]. WWTPs are energy-consuming, especially in terms of electric energy demand, that accounts for about 90% of their total energy consumption [2]. It has been estimated that WWTPs are responsible for 1% of the total national electricity consumption in European countries [3]. For each WWTP, electric energy accounts for 25–40% of total operating costs [4], of which 50 to 60% are connected to sludge treatment [5].

Over the last few years, the percentage of population connected to wastewater collection and treatment has increased, and more restrictive standards on the quality of water effluents have been introduced [6]. For these reasons, aging infrastructures are being upgraded and more advanced technologies are being adopted. As a consequence, energy consumption of water treatment is expected to increase in the near future. Despite that, energy efficiency and energy saving measures have not been largely implemented in wastewater treatment management [7], whereas recently, due to the increasing attention for the issue, energy consumption of WWTPs is also under investigation. Similarly to the residential and industrial sectors, energy audits can be carried out in WWTPs to analyse energy flows of the process and to identify measures to reduce energy consumption and carbon footprint. Indeed, energy use has been demonstrated to be a major source of carbon emissions in WWTPs [8].

The environmental impact of energy consumption in WWTPs can be reduced through different strategies, such as energy efficiency measures, use of renewable energy sources, energy recovery from wastewater and/or its by-products. Although combining energy efficiency actions and energy harvesting from wastewater has been demonstrated to be feasible for energy self-sufficiency in WWTPs, the majority of them still needs improvements to achieve net-zero consumption [8].

Energy consumption can be reduced through measures, such as programmed maintenance [9] and installation of real-time management systems [10], or through specific actions addressed to the largest energy-consuming stages. Furthermore, depending on the availability, different renewable energy sources can be employed in WWTPs [11]. Solar energy can be applied for sludge drying: the first application has been the use of solar drying beds [12], then replaced by greenhouse dryers [13], due to their higher efficiency [14]. Solar energy has been also coupled with biogas from anaerobic digestion, to produce electric energy, demonstrating the complete self-sustainability of the plant

* Corresponding author.
E-mail address: simona.difraia@uniparthenope.it (S. Di Fraia).

https://doi.org/10.1016/j.enconman.2018.02.058
Received 23 November 2017; Received in revised form 12 February 2018; Accepted 14 February 2018
0196-8904/

Nomenclature

Roman symbol

BOD	Biological Oxygen Demand (mg/l)
CAS	Conventional Activated Sludge (mg/l)
COD	Chemical Oxygen Demand (–)
DEA	Data Envelopment Analysis (–)
DO	Dissolved Oxygen (–)
EE	Electric Energy (kWh)
EPI	Energy Performance Indicator (kWh/kg)
GHG	GreenHouse Gas (kg CO_{2eq}/kWh)
KPI	Key Performance Indicator (–)
PE	Population Equivalent (inhabitants)
R^2	Pearson correlation coefficient (–)
SPI	Energy Self-Production Indicator (SPI) (–)
TN	Total Nitrogen (mg/l)
TS	Total Solids (mg/l)
V	Volume (m^3)
WC	Water Content (%)
WW	WasteWater (–)
WWTPs	WasteWater Treatment Plants (–)

Greek symbol

η	removal efficiency (%)

Subscripts

BOD	BOD
COD	COD
el	electrical energy
in	inlet
out	outlet
PE	population equivalent
SL	sludge line
SL&Tr	sludge line and transportation
SP	self-produced
th	thermal energy
TN	total nitrogen
Tr	transportation
TS	total solids
V	volume of wastewater

year-round [15]. The combination of solar energy and biogas from anaerobic digestion has been also proposed for sludge drying and electric energy production [16]. Moreover, several innovative treatments, based on solar energy have been developed for water purification. Sunlight driven photocatalytic ozonation has been found to be a low-cost and sustainable method of treating wastewater, especially in countries where sunlight is abundant [17]. Concentrating and non-concentrating solar reactors have been used for photo catalytic degradation of pollutants in industrial wastewater treatment [18] or in urban systems for further reuse in agriculture [19].

It has been estimated that the potential energy recovery from wastewater and/or its by-products could produce more energy than that required for the treatment [20]. Chemical energy of wastewater and bio-solids, deriving from their organic and nutrients content [21], can be exploited through microbial fuel cells [22], anaerobic digestion [23] or thermal treatment of sludge such as incineration [24] or gasification [25]. Thermal energy of wastewater can be also exploited for direct heat recovery through heat pumps [26]. Moreover, in case of sewage discharge from a higher to a lower point, wastewater hydraulic energy can be obtained [6].

WWTPs energy efficiency can be also enhanced by implementing performance criteria and incentives for plant managers [27]. For this reason, the energy performance of WWTPs needs to be assessed. Several specific indicators have been proposed in literature, which relate energy consumption to the main operation parameters of the process. The characteristics of influent wastewater play a fundamental role on treatment and as a consequence on the plant energy demand: high pollutant loads or high flow rates increase the energy demand of the biological phase and pumping, respectively, while highly diluted influents can cause operational problems [28]. Internal factors, such as equipment specifications, sludge imports, effluent quality and site footprint of WWTPs [29], as well as external factors influencing the energy demand, such as climate conditions or seasonal variation due to tourism [28], need to be considered to properly assess the energy performance of WWTPs.

For the sake of clarity the stages composing a Conventional Activated Sludge (CAS) system are illustrated in Fig. 1. CAS is the most common process for municipal wastewater treatment, especially for centralized facilities [30]. A conventional WWTP with CAS and anaerobic sludge digestion has an average electric energy consumption of

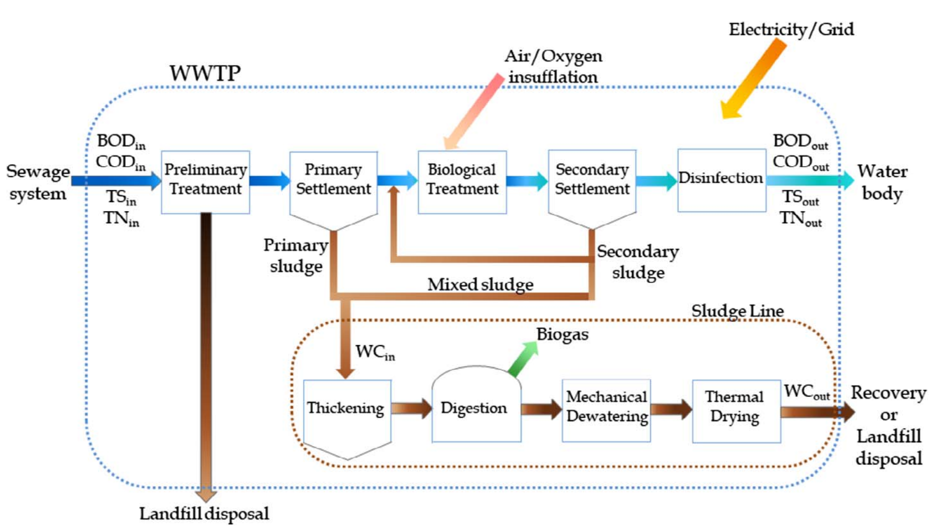

Fig. 1. Main stages of a CAS system.