Applied Energy 161 (2016) 404–411

Contents lists available at ScienceDirect

Applied Energy

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

Evaluation of the energy efficiency of a large wastewater treatment plant in Italy

Deborah Panepinto [a,*], Silvia Fiore [a,1], Mariantonia Zappone [a,2], Giuseppe Genon [a,3], Lorenza Meucci [b,4]

[a] DIATI (Department of Engineering for Environment, Land and Infrastructures), Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy
[b] SMAT (Turin Metropolitan Water Society), Corso XI Febbraio 14, 10152 Torino, Italy

HIGHLIGHTS

- The full scale energy utilization in WWTP has been defined.
- The energy efficiency of the plant corresponds to the best performances of large scale.
- The thermal balance from sludge digestion and drying has been considered.
- Improvement in energy efficiency had proposed.

ARTICLE INFO

Article history:
Received 4 June 2015
Received in revised form 21 September 2015
Accepted 1 October 2015
Available online 22 October 2015

Keywords:
Energy efficiency
Wastewater treatment
Biological oxidation
Aeration

ABSTRACT

Energy consumption represents a significant part of the operative costs of a wastewater treatment plant but, with a correct design and a careful management model, there are important possibilities for its limitation. The proposed research presents a multi-step methodology for the evaluation of the energetic aspects of wastewater treatment, which was implemented on the largest facility in Italy (2.7 M population equivalents as organic load), managed by Società Metropolitana Acque Torino (SMAT). The study initially took into account each phase of the process scheme, in order to obtain specific electricity consumption values for all the electro-mechanic devices. Data from tele-control system and direct measurements in field have both been acquired. The total electric energy demand of the plant was evaluated (66.78 GW h/y, about 50% from aeration in oxidation tanks). In account of large contribution the energy efficiency of the blowers was verified with positive results. Four specific energy consumption indexes were considered to carry out a critical analysis of SMAT wastewater treatment plant with other facilities performing biological oxidation processes and of a different order of magnitude about design capacity, and congruent values were obtained. The considered indexes related the electric energy demand to the equivalent population, to the volume of treated water and to the amount of removed COD and total Nitrogen. Furthermore the thermal energy demand of the plant was estimated (49.15 GW h/y, more than 93% from sludge line). An energy balance for the whole plant was finally evaluated, and some energy optimization solutions to decrease the corresponding costs were suggested.

1. Introduction

Wastewater treatment (WWT), removing biological and chemical pollutants from water, assumed a major role to protect the environment and public health. During the past years WWT plants have been developing the adopted technologies to increase the reclamation efficiency to comply with the discharge limits imposed by the law, which became year by year more restrictive.

The main concern of the WWT industry has always been to meet water quality standards in order to keep public trust [1]. Thus WWT plants are usually designed to meet certain effluent requirements, without any major energy considerations [2]. As a result, WWT plants were hardly ever designed with energy efficiency in mind [3–5]. However this attitude was definitely changing in the recent years, in the general framework of the achievement of 20-20-20 goals defined for Climate and Energy by Directive 2009/28/

* Corresponding author. Tel.: +39 011 0907632; fax: +39 011 0907699.
E-mail addresses: deborah.panepinto@polito.it (D. Panepinto), silvia.fiore@polito.it (S. Fiore), mariantonia.zappone@polito.it (M. Zappone), giuseppe.genon@polito.it (G. Genon), lorenza.meucci@smatorino.it (L. Meucci).
[1] Tel.: +39 011 0907613; fax +39 011 0907699.
[2] Tel.: +39 011 0907632; fax +39 011 0907699.
[3] Tel.: +39 011 0907660; fax +39 011 0907699.
[4] Tel.: +39 011 4645097; fax +39 011 4365575.

http://dx.doi.org/10.1016/j.apenergy.2015.10.027
0306-2619/

E [6]. As before mentioned, an improvement in pollutants removal (particularly nutrients and organic matter) is required by current regulations, thus leading to enhanced WWT processes. Moreover, considering the diffuse trend to the centralization of WWT in highly populated metropolitan areas, the optimization of energy efficiency of WWT is without any doubt a crucial issue for managing companies.

It is known from literature and managing experience [4,7,8], that in a conventional WWT plant about 25–40% of operating costs is ascribable to energy consumption. This value varies in the range of approximately 0.3–2.1 kW h/m^3 of treated wastewater [9].

The main contributes to energy consumption in a conventional WWT plant typically are the aeration of mixed liquor (55–70%), primary and secondary settling with sludge pumping (15.6%) and sludge dewatering (7%) [4]. About aeration, it may be expected that the installation of proper control devices on the blowers and/or efficient blowers could decrease their energy demand of up to 0.04 kW h/m^3 of treated wastewater [4]. Considering the type of implemented biological process, comparing WWT plants of analogous potentiality (above 100,000 m^3/d), an increase up to 50% in energy consumption may be observed comparing an advanced biological treatment (with nutrients removal and filtration) with a conventional active sludge process [4]. Other important issues, more connected to management aspects, that may decrease energy efficiency are a not correct maintenance of electro-mechanic devices, the presence of infiltration surface rainwater in the sewer network (which burden the inflow rate and dilute the organic load), and any anomalous hydrodynamic behavior of the reactors.

Energy efficiency optimization in WWT is a rather popular topic in the scientific community. In particular Descoins et al. [10] pointed out that so far the wastewater-modeling experts focused on modeling the effluent characteristics, while the implicit energy aspects received very little attention. Fikar et al. [11] analyzed the energy efficiency optimization with reference of different activated sludge processes, whilst Holenda et al. [12] focused on aeration. The economic and environmental sustainability performances of several typologies of WWT plants performing biological processes were studied in Spain, in Portugal [13], in Norway and in Australia [14].

Several researchers [7,15,16], considering energy efficiency in WWT from a more general point of view, discussed the potential of wastewater as an energy carrier, in view of both chemical and thermal energy recovery perspectives. For example Molinos-Senante et al. [6] studied the optimization in the energy production from wastewater treatment plant and the generation of substitute natural gas (Bio-SNG) from the biogas obtained from the anaerobic digestion process. Cano et al. [17] examined, with a review work, the energy optimization from wastewater treatment plant using several sludge pre-treatment before the anaerobic digestion process. Energy consumption and GHG emissions of different scenarios of sewage sludge treatment systems were analyzed by recent studies [18,19], wherein the effectiveness in reducing GHG emissions of the use of biogas for the energy needs in WWT processes was emphasized. Eastern Research Group Inc. [20] discussed the development of CHP facilities at 554 WWT plants in the USA. A main finding of the study was that there was a real convenience in the installation of CHP units for facilities having inflows above 18,500 m^3/d and performing anaerobic digestion of sludge. Bidart et al. [21] developed an approach in order to measure the CO_2 shadow price for wastewater treatment in fact the estimation of the value of carbon emissions has become one of a major research and policy topic since the establishment of the Kyoto Protocol.

In other papers [22–25], energetic aspects connected to indirect energy use, external production of energy, production of chemicals were considered, leading to a general estimation of meaning of the technology in terms of life cycle analysis. In this paper, on the contrary, the attention has been devoted to industrial aspects and operative economic considerations, consequent to direct in–plant energy consumption and to the use of energy that is directly generated. So the perspective of this approach is different from the LCA one, and it seems to be more pertinent with respect of the direct exploitation of the plant and the practical interest of the operators.

The present study has the purpose to propose a multi-step methodology for the evaluation of WWT energy efficiency, considering the complex framework of a biological process completed by biological and physic-chemical tertiary treatments. The research exhibits several novelty issues with respect of the previously cited studies. First, many of them are focused on specific aspects of WWT, missing an overview of a complete and composite treatment process. Secondly, another main group of studies on the contrary consider the overall energy and environmental features of WWT from a general point of view (mainly based on LCA approach) that describes the considered case studies. The present research follows the opposite path, presenting a general methodology, applicable to any case study, which was validated through the implementation on the largest Italian WWT facility (about 2.7 M equivalent inhabitants). The field data were collected in 2012–2013 with a special focus on the energy consumed by each operational phase in the plant, in order to find out the most expensive and to investigate the possible solution to obtain an economic advantage.

2. SMAT wastewater treatment plant of Castiglione T.se

SMAT, that is the Turin metropolitan water society, manages in Turin metropolitan area (which covers about 450 km^2 and 2.2 M inhabitants) a WWT plant operating on about 615,000 m^3/d of municipal and industrial wastewater, corresponding to a an organic load potentiality of 2.7 M of equivalent inhabitants. The process is schematized in Fig. 1 and fully described elsewhere [26].

The water line performs primary, secondary and tertiary treatments (biological for nitrogen removal and chemical for phosphorous removal) on four parallel process lines (or modules), while the reclaimed water is mainly discharged in Po River and it is in part reused in agriculture or for industrial purposes by means of a 5 km industrial network.

The sludge line capacity corresponds to about 6000 m^3/d (2% d.s.). After a pre-thickening phase, sludge undergoes anaerobic digestion, post-thickening and mechanical/thermal drying.

3. Methodology

The research was performed implementing the following multi-step approach:

(1) *Inventory of all the electro-mechanic devices operating in the plant*. The process was assisted by the tele-control system of the WWT plant, which allowed the localization of the single devices for each of the four lines. All the main electro-mechanic equipments have been included in the survey, with the exception of the electrical valves, because it was assumed that such energy use could be negligible in comparison to the other devices;

(2) *Evaluation of the electric energy absorption of the electro-mechanic devices*. Subsequently, on the field, the data on the label of each electric equipment (i.e. power, voltage, power factor) that are necessary to calculate its energy consumption were collected. Another variable, which is necessary to determine the energy used by certain equipment, is the operating time. When the information was not available from the tele-control system, it was obtained from interviews with the technical staff in