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Tools for optimizing the operating conditions of waste-to-energy plant

ABSTRACT

The efficient use of energy and resources is important from the point of environmental responsibility, but at the same time, it can be an opportunity towards obtaining economic value. Waste-to-energy (WtE) plants have the dual objective first to reduce the amount of waste sent to landfills, and second to generate electricity, heat and biogas. Tracking the flows of energy and materials within WtE system could be convenient optimization tool for waste treatment process. Through modeling and simulation of complex operating systems, it is manageable to present the actual operation states and conditions, and in case of modified operation conditions, possible treatment results. To achieve better operating performances chosen models can analyze, adjust and improve the WtE process in accordance to desired parameters. This paper gives an insight of some of the most adequate tools for modeling of WtE plants.
Keywords: *Waste-to-energy, tools, optimization.*

1. INTRODUCTION

The large amounts of waste that stream from different aspects of human production and consumption activities, cause an increased demand for effective waste management. On the other side the global need for energy of various power generation systems, incorporated waste as important energy source. It is anticipated that market of energy obtained from waste will grow at a rate of over 7% by 2025 [1].

Waste-to-energy (WtE) technologies manage solid municipal waste and recover energy from it. The family of WtE technologies incorporates municipal solid waste incineration, co-processing, anaerobic digestion for biogas production, capturing of landfill gas, and alternative technologies: pyrolysis and gasification. WtE plants defined by waste treatment pathways [2] are:

- *Combustion plants* which utilize waste as a secondary energy source in combination with other types of fuels (these installations include all kinds of conventional power plants used for the generation of mechanical and/or electrical power generation and heat, as well as recovery boilers)
- *Waste incineration plants* dedicated to the thermal treatment of waste, with recovery of the combustion heat, through the direct incineration by oxidation of waste
- Cement and lime production plants
- Anaerobic digestion plants
- *Other waste-to-energy plants* (including pyrolysis / plasma treatment, gasification plants and hazardous waste incineration plants).

The most common WtE technology used worldwide is municipal solid waste incineration in a moving grate combustion system with combined heat and power production (CHP), while modern WtE has dual functions. The pyrolysis, gasification and plasma arc gasification, are relatively new process for WtE application, with limited installations globally (investments costs is the obstacle for wider engaging of these technologies).

Monitoring and optimizing the WtE processes can help to accomplish rising process efficiency, achieve better operating performances, obtaining more energy from the same amount of waste. Sometimes modeling and simulation of processes can offer easy-to-implement solutions for upgrading existing systems.

The study of the EU Commission estimates that with if proven techniques and supporting measures are implemented properly, the amount of energy recovered from waste could rise by 29 %, having the same amount of waste as raw material [3].

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2. WTE SYSTEMS AND TOOLS SELECTION

The best proven techniques to increase energy efficiency for the WtE processes according the founding of the EU Commission study are [3]:

- *Co-incineration in combustion plants*: gasification of solid recovered fuel (SRF - fuel produced from non-hazardous waste in accordance with EU standards) as well as co-incineration of the resulting syngas in the combustion plant (in order to replace fossil fuels in the production of electricity and heat);
- *Co-incineration in cement and lime production*: conversion of waste heat to power in cement kilns;
- *Waste incineration in dedicated facilities*: the use of super heaters; harnessing the energy contained in flue gas; the use of heat pumps; supplying chilled water for district cooling networks; and distributing heat from waste through low temperature district heat networks;
- *Anaerobic digestion*: upgrading of the biogas into bio-methane for further distribution and use (e.g. injection into the gas grid and transport fuel).

Obtaining maximum energy from any WtE processes within operation plants could be manageable by mean of a conveniently chosen optimization tool for waste treatment, tracking the flows of energy and materials. These tools (software products) ought to be applicable for several different purposes:

- For presenting the actual operation states and with actual working conditions,
- For simulation of possible treatment results in cases of modified operation conditions (e.g. after changes or technical alterations in waste input, or the change of operation settings) [4].

The most common WtE technology used worldwide is the incineration of municipal solid waste in a moving grate combustion system with combined heat and power production (CHP), while modern incinerators have dual functions. The document *Best available techniques reference document on waste incineration* [5] suggests that it is necessary to consider the energy required by the process itself and the possibilities for exploitation, because increasing the energy output does not, solely, equate to the energy conversion efficiency. The factors that need to be taken into account when determining the optimal energy efficiency are [5, 6]:

- Location. The presence of a user/distribution network for the energy provided.
- Demand for the energy recovered. This is a particular issue with heat but generally less of an issue with electricity.
- Variability of demand. Summer/winter heat requirements will vary for example.
- Climate. In general, heat will be of greater value in colder climates.
- Local market price for the heat and power produced. A low heat price will result in a shift to electricity generation and vice versa.
- Waste composition (e.g. concentrations of corrosive substances, seasonal composition changes, etc.).
- Waste variability. Fluctuations in waste composition can give rise to fouling and corrosion problems over the plant life.

The actual operation conditions can be calculated [7] and visualized after the model is fed with waste material and process data. In the case of modified operation conditions, possible treatment results can be simulated. Once the models have been complied and fed with data, the actual operation conditions and states can be calculated and visualized [8].

Table 1. The tools and databases based on life cycle thinking [9-11]

Tabela 1. Alati i baze podataka bazirani na praćenju životnog ciklusa [9-11]

Tools and Databases	Developer	Description
GaBi	PE International GmbH	Support product life cycle assessment (LCA)
SimaPro	PRé Consultants B.V.	
openLCA	GreenDeltaTC GmbH	
TEAM	Ecobilan - PricewaterhouseCoopers	
EIO-LCA	Green Design Institute, Carnegie Mellon University	
Umberto LCA+	Ifu Hamburg GmbH	
Umberto Efficiency+	Ifu Hamburg GmbH	Support substance and material flow analysis (SFA/MFA)
Sankey Editor	STENUM GmbH	
STAN	Vienna University of Technology	
Ecoinvent	Swiss Centre for Life Cycle Inventories	Compile process input/output data for materials and energy
US LCI	U.S. National Renewable Energy Laboratory	
DEAM	Ecobilan - PricewaterhouseCoopers	

Table 1 summarizes several most in use tools and databases based on life cycle thinking that can be applied to WtE.

Life cycle assessment (LCA) is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction, through materials processing, manufacture, distribution, use, repair and maintenance. Since the first attempts to use the tool were made in the late 1960s, it has gained in popularity and been used in many contexts, such as to assess waste management systems [12]. There are now dozens of software for analyzing of LCA, and the first was developed by SimaPro software in the early 1990s and has been used extensively within the recent decade to evaluate the environmental performance of thermal Waste-to-Energy (WtE) technologies (Fig.1): incineration, co-combustion, pyrolysis and gasification [13].

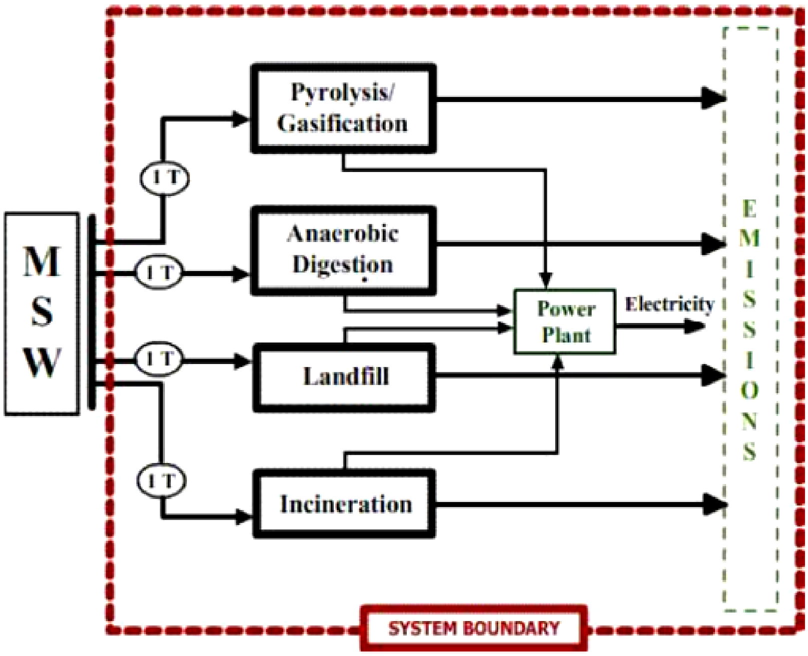

Figure 1. System boundary of the LCA model [14]

Slika 1. Granice sistema prema LCA modelu [14]

The LCA tool alone cannot evaluate all various WtE options and cope with the contemporary need of obtaining sustainability assessment (including economic and society challenges) [15,16], as the outcome, new tools were developed, based on the LCA structure (Table 1) and still are under continuous development. These tools in some cases have so to call “light” versions marketed to non LCA experts (note: GaBi, SimaPro and Umberto) in addition to professional one [11]. LCA tools that allow the user to import new impact methods can also calculate “Material Footprint” (or: Material Input Per Service, MIPS)[11]. These LCA software products may include different databases [18] but the most frequent one in use, available to support data input, is the Ecoinvent database (Life Cycle Inventory database). Though the Ecoinvent database still does not provide sufficient input flows for the calculation of the all needed MIPS [11,17].

STAN software. In the case of STAN, a graphical user interface (GUI) allows comfortable defining of even complex systems. STAN is freely available software. It supports MFA (Material Flow Analysis) and SFA (Substance Flow Analysis), enables the consideration of data uncertainties, and can be used as a base for modelling for the assessment of the economic resources, and environmental values of materials [19]. System components can be chosen freely and are referred to as products, raw materials, pollutants, forms of energy, and so forth, and are organized in a hierarchically structured material list [20].

For incinerator plant major inputs can be: municipal solid waste (MSW), electricity, additional fuels like diesel, natural gas or coal, water and activated carbon (for control of air pollution), with the outputs: flue gas (HCl, SO_2, NO_x, dioxins, CO, PM10, HF), bottom ash, iron scrap, electricity generated, water discharge and air pollution control residues [21].

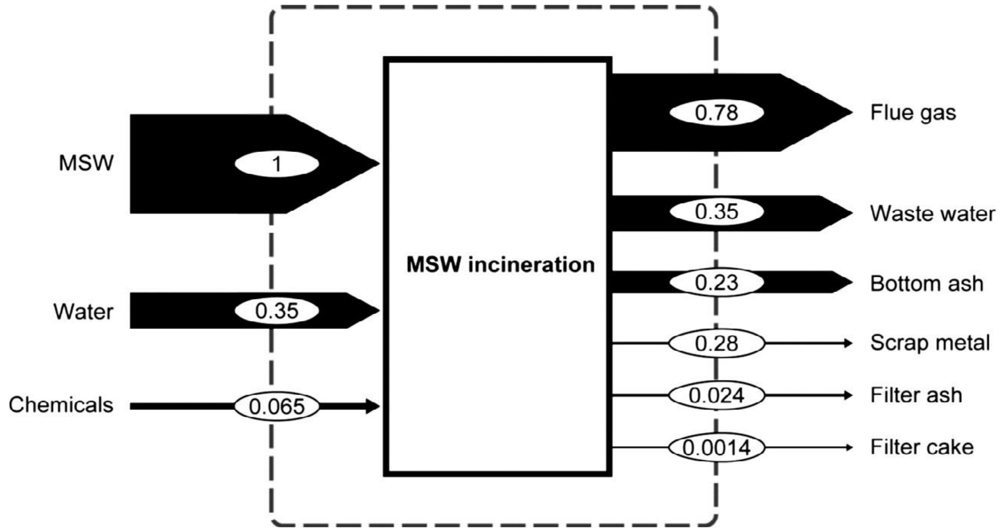

Figure 2. Typical mass flows through a WtE plant obtained by STAN [20]

Slika 2. Tipičan maseni protok unutar postrojenja za dobijanje energije iz otpada primenom alata STAN [20]

Figure 2 shows example of the typical mass flows through a WtE facility equipped with dry electrostatic precipitator and wet air pollution control systems, in kg per kg of municipal solid waste. In addition to the flows presented in this figure, about 5 kg of air are required for combustion, increasing the amount of flue gas by the same extent [20].

As the bottom ash typically represents 15–30% of the input waste mass in waste incinerators, STAN software can also be applied to obtain prediction and calculations of its quantities and qualities [22, 23].

Umberto is a complex tool for supporting process optimization during manufacturing or along a product life cycle (product scale).

It visualizes a process model that can be assessed according to different evaluation criteria and allows subsequent optimization of the process. The Umberto product family can be applied on issues connected with integrated resource efficiency, as well as, for integrated environmental assessments, incorporating [10]:

- Material flow analysis to increase material and energy efficiency
- Cost accounting to determine potential savings in production or with integrated ecological evaluation for eco-efficient decisions(life cycle costing)
- MFCA to calculate the true cost of material losses (Fig.3)
- CO_2 balances for tracking and achieving climate targets or determine the climate impact for products and companies
- Life cycle assessments for calculation of all environmental impacts over the product life cycle.

Most important Umberto's features are graphical modeling of process systems, visualization of material flow quantities, scenario analyses and detailed cost accounting. The optimization cycle managed by Umberto offer savings in the areas of production utilities costs of waste disposal, gaseous and liquid effluent treatments; raw material costs (wasted materials must be obtained in the first place); handling, storage, administration environmental loads [10].

It is important to mention that several other tools (e.g. openLCA, SimaPro, GaBi) also support “cost flows” (user can define a new impact category adding up the costs), therefore can be used for Life Cycle Costing (LCC) [10,11].

The optimization cycle within Umberto usually has six steps [24]:

1. Problem definition (what is happening, where, how much is being transformed, and why?);
2. Flow analysis (measurement, system description, situational analysis, material and energy flow analysis, and cost analysis);
3. Data assessment (where are the potentials for cost savings and system optimization?);
4. Scenario variations (system modeling using mass and energy balances);
5. Development of optimized processes;
6. Implement measures.

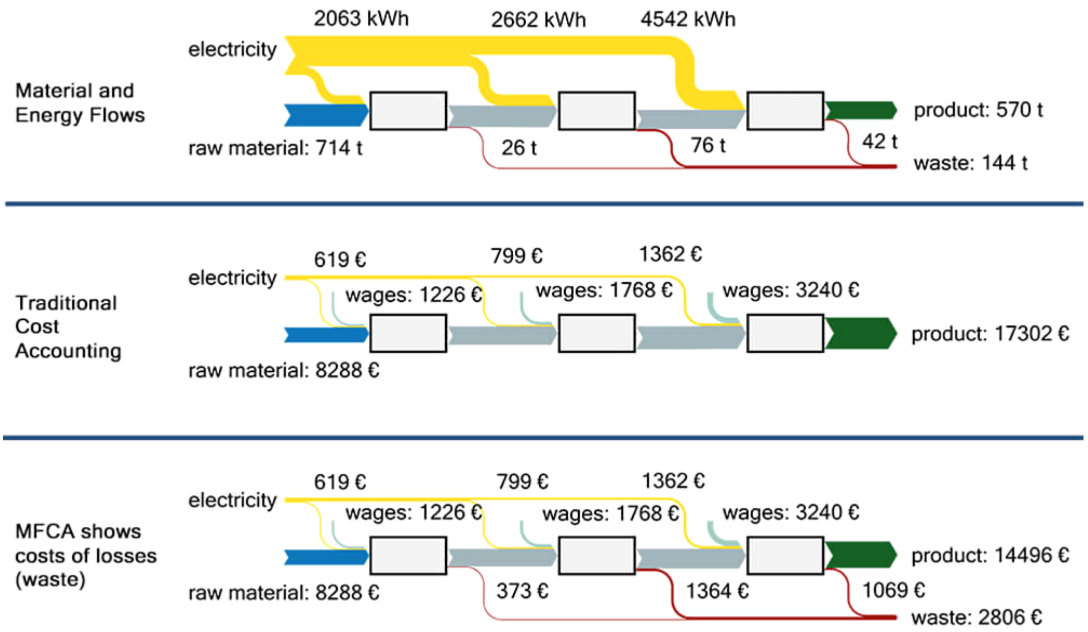

Figure 3. The difference between the traditional cost accounting and material flow cost accounting (MFCA) within Umberto simulation - example [10]

Slika 3. Poređenje tradicionalnog proračuna troškova i proračuna koji u obzir uzimaju tokove materijala - primer primene alata Umberto [10]

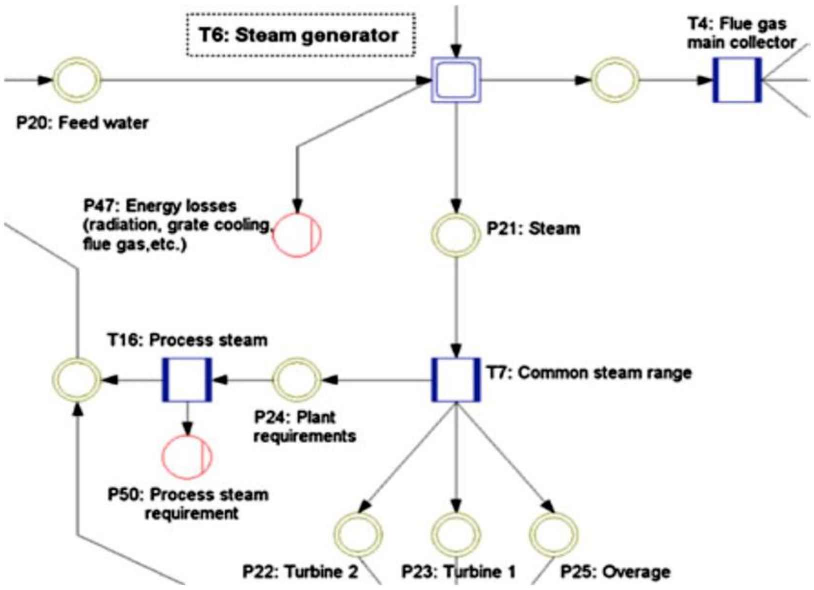

Figure 4. Steam generation section of a WtE plant obtained in Umberto – example. [25]

Slika 4. Primer prikaza sektora za generisanje pare energetskog postrojenja (UMBERTO alat) [25]

With Umberto, modeling a plant as a material flow network, all process steps can be described in detail, their treatment purposes have to be shown and potentials for the optimization be indicated (example at Fig.4). Specific optimization strategies for several approaches can be established, e.g. adjusting plant configurations, determining the optimal waste mixture or deducing strategies for managing material flow in order to reach optimal treatment results [24,25].

3. CONCLUSION

The flows of energy and materials within the WtE systems require constant monitoring, and processes optimization, with focus on improvement of operation conditions, structuring and managing waste streams, developing specific WtE processes strategies, finding the most efficient and environmental friendly treatment options, with minimized health risk. As of today, a significant number of specialized software products (tools) have been developed on a basis of MFA and LCA methodology, but with different potential for aplication on WtE systems. This paper gave short overview of several frequently used tools for the WtE plants. Tools developed on MFA concept explicitly do not include environmental assessment (so with them qualitative and quantitative assessment can be obtained – e.g. STAN software), while others, based on LCA methodology, can performe the environmental assessment through the quantification of environmental effects (e.g. with GaBi, SimaPro, openLCA, Umberto). Software's graphical modeling of process systems, visualization of material flow quantities, scenario analyses, analyzing and prioritizing some key criteria, and in some cases, detaile cost accounting, can support and ease decision-making process.

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IZVOD

ALATI ZA OPTIMIZACIJU RADNIH USLOVA POSTROJENJA ZA ENERGETSKO ISKORIŠĆENJE OTPADA

Efikasno korišćenje energije i resursa važno je sa stanovišta odgovornosti za životnu sredinu, ali istovremeno treba imati u potencijalnu ekonomsku dobit. Postrojenja za proizvodnju energije iz otpada (eng. Waste-to-Energy, WtE) imaju dvostruki cilj, da smanje količinu otpada koja se šalje na deponije, kao i da omoguće proizvodnju električne energije, toplote i biogasa. Praćenje protoka energije i materijala unutar ovih postrojenja, može da predstavlja praktičan alat za optimizaciju tretmana otpada. Pomoću modeliranja i simulacije složenih operativnih sistema, moguće je prikazati stvarna radna stanja i uslove procesa, a u slučaju izmenjenih uslova rada i moguće rezultate tretmana. U cilju postizanja boljih operativnih performansi, odabrani modeli mogu vršiti analizu, mogu prilagoditi i poboljšati proces dobijanja generisanja energije iz otpada u skladu sa željenim parametrima. Ovaj rad daje uvid u neke od najprikladnijih alata za modeliranje postrojenja za dobijanje energije iz otpada.

Ključne riječi: *Energija iz otpada, alati, optimizacija.*

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