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Waste-to-Energy (W2E) software – a support tool for decision making process

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This paper deals with the issue of effective treatment of sewage sludge from waste water treatment plants (WWTP). Application of specific computational tool is demonstrated on a case study; it reveals effective ways of thermal treatment of sludge produced in a particular WWTP for a city with a population of one million. Hand-tailored Waste-to-Energy (W2E) software, that is being developed, is applied for computations based on energy and mass balances. This software is briefly introduced and described in the paper. With support of this software several technologies for thermal treatment are analyzed in terms of energy consumption and/or production. Sensitivity analysis of these systems is carried out in order to find effective energy utilization. The evaluation of local and global environmental benefits (i.e. primary energy savings, emissions) is taken into account as well. The data and results of the performed analysis form the basis for the plant enhancement which is planned in near future.

1. Introduction

Nowadays, a lot of attention is paid to alternative sources of energy. Rapidly developing waste to energy process is a case in point. Sewage sludge is produced as a by-product of water cleaning in wastewater treatment plant (WWTP). The main ways of sludge utilization are reclamation and composting. Because these methods are becoming out-of-date, the focus is on using sludge as a source of energy. Due to the planned WWTP intensification an analysis of various approaches of sludge utilization for energy production needs to be performed at the design stage in order to find out which approach seems to be most effective. Sludge is supposed to be incinerated in a local waste-to-energy plant (WTEP). Further decisions can be made according to the results.
Simulation program W2E calculates energy and mass balances of simulated process. It is designed for waste to energy process but can be used for simulation of various technological processes as well. W2E can be very easily extended of new technological nodes or streams, which makes this software very versatile.

2. Thermal treatment of waste process simulation

Typical system for thermal treatment of waste is divided into several subsystems such as incineration section, heat recovery section, etc. Every subsystem consists of equipment which may differ according to requirements of a particular process (different for solid and liquid waste incineration).
Software systems for simulation are based on mathematical modelling. Systems calculating energy and mass balances use either sequential-modular or equation based

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approach (or their combination) (Felder and Rousseau, 1999). The design of the process consists in creating flow sheet with using technological blocks. Blocks are connected by streams and can create more complex apparatuses.

2.1 Modeling and simulation in W2E

W2E software is a supporting tool for technological process simulation. It has been developed in Java and provides user-friendly environment and intuitive operating. Principle of modelling and simulation is the same as in other similar systems. It consists in creating flow sheet (graphical representation of the process), setting data and running simulation. W2E uses sequential-modular approach for computations so calculation moves from one unit to another until all units are covered. Some of the features of W2E are listed below:

- Setting input data is very comfortable because almost everything may be set in side panel in the main window; no extra windows are needed.
- Checking computed values (temperature, enthalpy, composition) is very easy due to the watching tables. They are displayed on the right in the flow sheet. The user may choose which parameter, stream or block is to be displayed.
- Easy extension of new blocks and streams is possible. Source code is designed so that their addition consists of few steps and no advanced programming skills are needed.

W2E also provides simulation of processes with cycle and export of data to Excel worksheet. Developing of W2E is still in progress so new functions are being added.

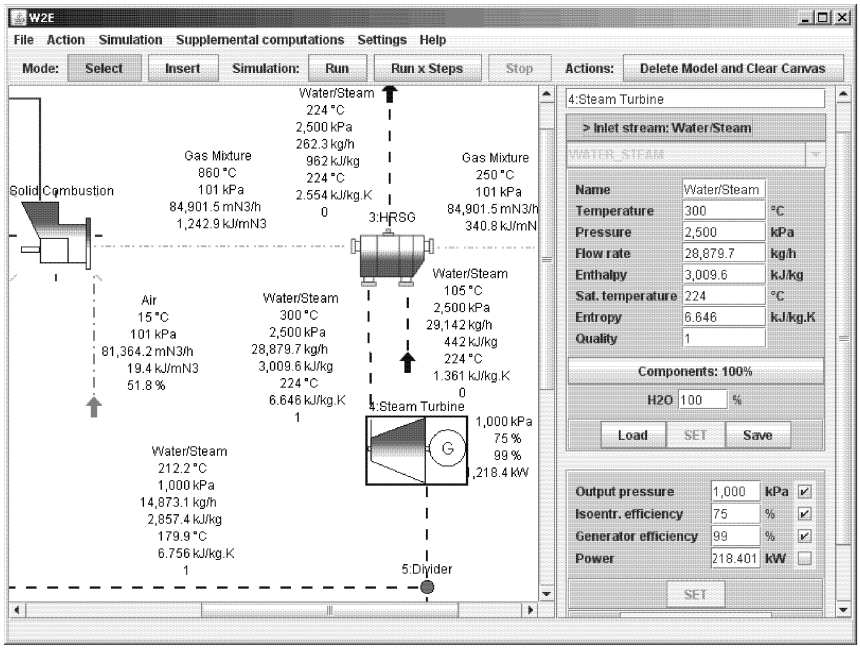

Fig. 1: User interface of W2E software

3. Case study – sludge utilization for energy production

Intensification of WWTP will result in increased sludge production. This is the reason why various alternatives of technological solutions of sludge utilization are considered. The wastewater treatment process is shown in Fig. 2. The output of this process is either dewatered mixed raw sludge (MRS) or dewatered digested sludge (DS) and biogas. All the products can be used as a fuel.

This case study is focused on sludge utilization as a source of energy from the electrical energy production point of view. Sludge is considered to be incinerated for the purpose of steam generation and subsequent electricity production. Both MRS and DS have to be dried since they contain about 67 % of water and their lower heating value is insufficient for incineration without extra fuel. DS drying can be done either in WWTP or in WTEP. Sludge digesting produces biogas which is very calorific (about 22 MJ/mN3) fuel. Biogas can be used in cogeneration unit (gas turbine) for heat and electrical energy production. Location of WWTP limits technological extensions therefore sludge incineration is considered to be performed only in WTEP. This fact has to be included.

3.1 Alternatives

3.1.1 DS1

This alternative considers drying in WWTP by energy from biogas. Flue gas produced by biogas combustion heats thermal oil - the drying medium. After the heat exchange flue gas is used to preheat combustion air. It means that less amount of electricity is produced in gas turbine but it saves steam which is used for electricity production on steam turbine. It also saves transport cost of sludge from WWTP to WTEP (drying significantly reduces amount of sludge) but this topic is not the object of this paper. This process is shown in Fig. 3 (without gas turbine).

3.1.2 DS2

In DS2 approach all biogas is used in cogeneration unit and dewatered sludge is transported to WTEP where it is dried. The drying medium is steam at the outlet of the first stage of steam turbine. Part of the steam is used for drying and the rest continues on condensing turbine. Process is shown in Fig. 4 (without gas turbine).

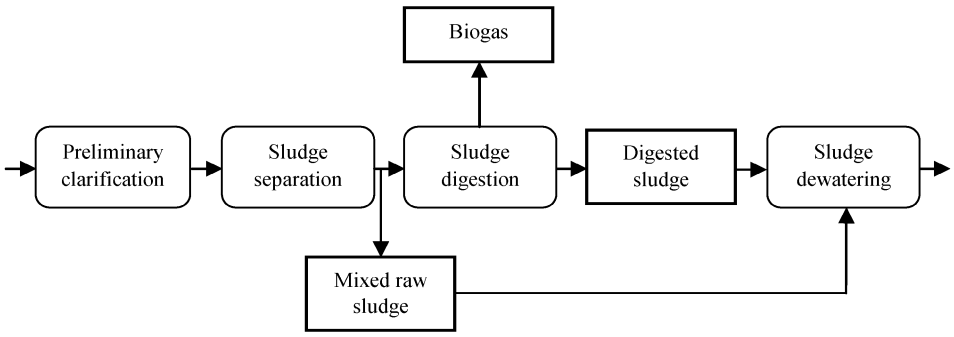

Fig. 2: Waste water treatment process

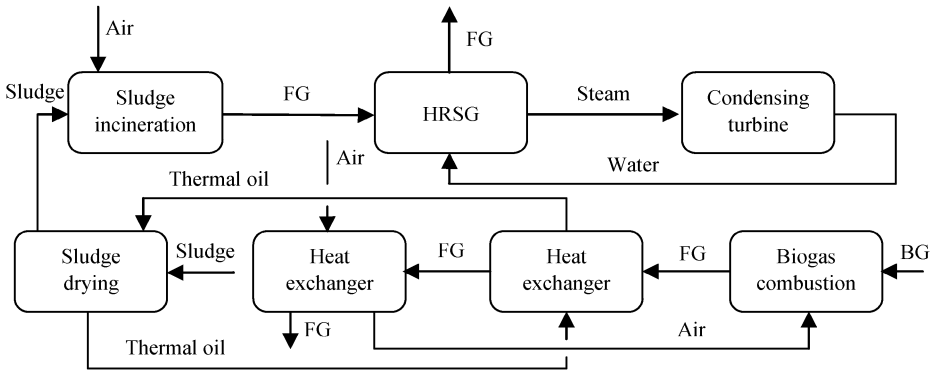

Fig. 3: DS1 process (FG = flue gas, BG = biogas)

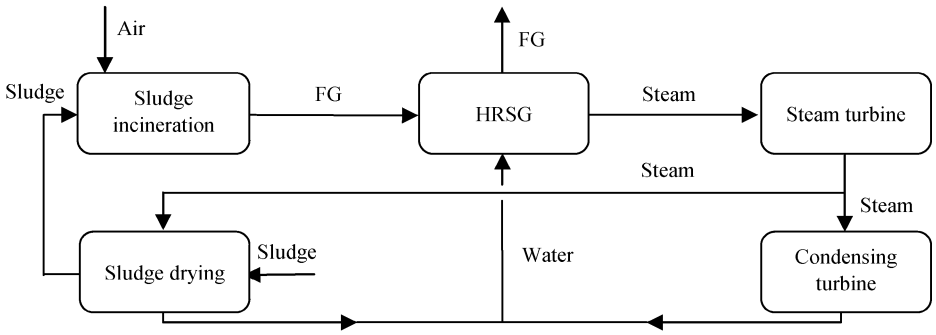

Fig. 4: DS2 and MRS process

3.1.3 Mixed raw sludge

Since there is no biogas produced there is no way to dry sludge in WWTP without extra fuel. Considering WWTP tends to be as self-sufficient as possible, dewatered sludge has to be transported to WTEP, dried there and then incinerated. Flow chart of this process is similar to DS2 and is shown in Fig 4.

3.2 Parameters of simulated processes

Some process parameters were being changed to find out their influence on electricity production. The parameters were ratio of dry mass in sludge and output pressure of steam at the outlet of the first stage of steam turbine (mentioned as output pressure in the following text). Sludge drying is performed in order to incinerate sludge without extra fuel. The minimal lower heating value is assumed to be about 6.5 GJ/kg which is achieved when it is dried up to 50% and 60% of dry mass for MRS and DS respectively. Even thought simulations with sludge dried to this level are included the material is not acceptable for incineration because it causes heavy fouling and practically it is impossible to use it for this purpose. Output pressure was being decreased from 1000 kPa down to 500 kPa when steam saturation temperature was higher than 150 °C.

3.3 Results

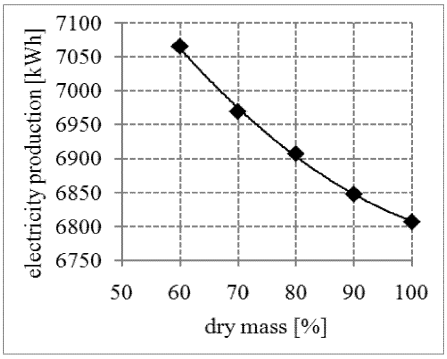

Fig. 5: DS1 (electricity-dry mass: 15 kPa pressure at the outlet of condensing turbine)

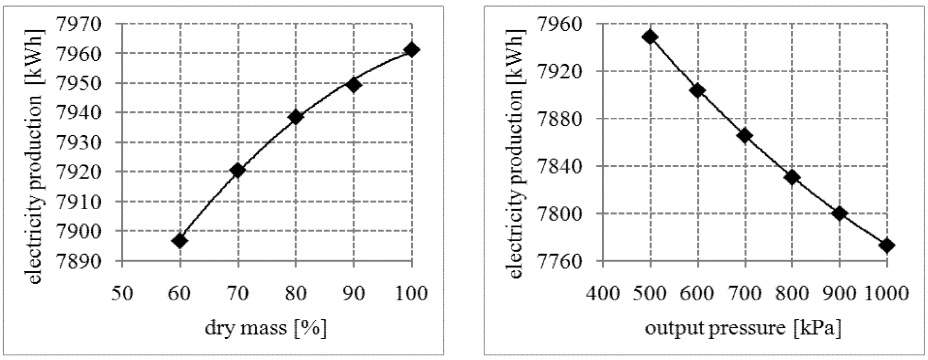

Fig. 6: DS2 (electricity-dry mass: 500 kPa output pressure; electricity-output pressure: 90% dry mass)

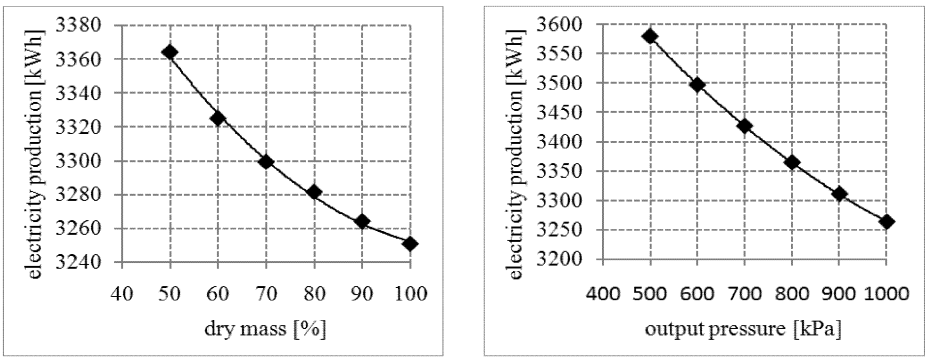

Fig. 7: MRS (electricity-dry mass: 1000 kPa output pressure; electricity-output pressure: 90% dry mass)

3.3.1 DS1 alternative

Actually this alternative compares electricity production on steam turbine and electricity production on gas turbine. Since steam turbine produces much less electricity than gas turbine biogas for cogeneration is responsible for most of the electric production. Results are shown in Fig. 5.

3.3.2 DS2 alternative

In agreement with the previous results more electricity is generally produced in this alternative because all the biogas is used for cogeneration. It is shown in the first graph in Fig. 6 that using steam in condensing turbine is not as beneficial as using it for drying. Second graph (Fig. 6) shows how electricity production changes with decreasing output pressure. Obviously the best configuration is 100% dry mass and 500 kPa output pressure.

3.3.3 MRS alternative

This alternative gives the lowest values of electricity production. The influence of dry content has opposite trend as in the case of DS2 and is more significant. While the dependency of electricity production on output pressure follows a similar trend. Fig. 7 shows the results.

4. Conclusion

Due to the planned intensification of WWTP and current trends the sludge produced in waste water treatment process was considered as a source of energy (this paper considers only electrical energy production). Three alternatives of sludge utilization for this purpose were designed. The experiments with the model of every alternative were performed in W2E software, which is a newly developed tool for modelling and simulation of technological processes. The best solution seems to be the alternative DS2 with configuration 100 % dry and 500 kPa output pressure producing 7961,46 kWh while the alternative MRS with configuration 100 % dry mass and 1000 kPa output pressure gives the worst value 3250,55 kWh.

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