Waste-to-Energy Plant Integrated into Existing Energy Producing System

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The EU directive on waste management from 2008 brings significant changes in waste treatment in many member states. For example, the Czech Republic agreed that by 2020 landfilling of biodegradable waste (BDW) will be decreased by 65% compared to 1995. Municipal solid waste (MSW) contains about 50 to 55 % of BDW and therefore significantly contributes to BDW production. Due to its advantages and the lowest impact on the environment, MSW incineration with heat recovery (WTE) is one of the preferred waste treatment options. In addition to waste disposal there is a potential of energy production and contribution to primary energy savings. Installed capacity of three Czech incineration plants is 616 kt/y. To meet the EU target the Czech Republic needs to increase the capacity of incineration plants (thermal treatment) by 1500 kt/y if current production is considered.

This paper is focused on integration of WTE plant into an existing heating plant with installed capacity of nearly 500 MW. The system is investigated from the energy and economic points of view. An advanced approach applying optimization procedure (in GAMS software) is used to deal with problem of WTE integration. The objective is to support decision-making process of a new plant by finding fundamental design parameters of the integrated WTE plant (annual capacity of the WTE plant - amount of waste processed, distance of waste collection, gate fee, heat utilization strategy etc.) and other parameters (identification of heat flows through the plant) essential for economic analysis.

1. Introduction

The EU directive on waste management from 2008 brings significant changes in waste treatment in many member states. New hierarchy for waste disposal has been introduced and should be implemented by member states. Many of them agreed with new targets according to the waste management hierarchy. For example, the Czech Republic agreed that by 2020 landfilling of biodegradable waste (BDW) will be decreased by 65% compared to 1995. Municipal solid waste (MSW) contains about 50 to 55 % of BDW and therefore significantly contributes to BDW production. Due to its advantages and the lowest impact on the environment, MSW incineration represents one of the preferred waste treatment options. It significantly reduces volume of the MSW which is landfilled and in addition there is a potential of energy production and contribution to primary energy savings. Considering current waste production in the Czech Republic it means to increase capacity of incineration plants (thermal treatment) by 1500 kt/y to meet the target, which seems to be very challenging.

This paper deals with the problem of integration of WTE plant into existing energy producing system from financial feasibility point of view. There is no focus on technologies used in WTE plants (for comparison of different technologies see work by Poma et al. (2010)). Luoranen and Horttanainen (2008) have evaluated feasibility of such integration using simple model of the system. In this paper more complex model is applied (e.g. specific investment cost of capacity is not constant, etc.). On the other hand more complex model may lead to time-consuming computations. The problem of operation planning is also formulated in a different way. In the present paper, the design parameters of the WTE plant are proposed and then technical economic optimization of the operation of the integrated system is performed. The approach is demonstrated on a case study involving real energy producing system. This paper refers to effective biomass integration into existing energy producing system presented in work by Touš et al. (2010).

2. Integrated System

The considered integrated system consists of the heating plant and waste to energy plant. The heating plant included in the case study satisfies two thirds of the demand for heat and cold in a city of nearly 200,000 inhabitants. Electricity is produced simultaneously. The plant provides delivery of heat to residential areas, public institutions, and a regional hospital as well as to industrial enterprises. For more details see works by Drápela et al. (2009) and Touš et al. (2010). The heating plant, in its current operation, focuses on renewable utilization - it co-fires coal and biomass. Future plan is to extend the system by heat delivery from WTE unit to decrease the dependence on fossil fuels and increase the share of renewable/alternative fuels.

The WTE plant is supposed to produce heat and electricity in turbine house equipped with condensing turbine with extraction. This cogeneration system is modeled as one

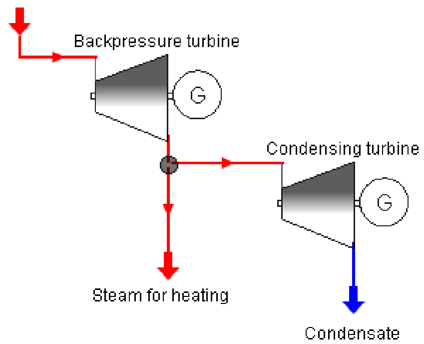

Figure 1: Schema of the turbine house in WTE plant

backpressure turbine and one condensing turbine (see Fig. 1). The maximal load of the condensing turbine (condensing stage) has to be designed with respect to variable heat and electricity demand, limited operation area of the turbine house of existing heating plant and nearly constant amount of MSW processed. In other words, operation of the WTE plant should be adaptable enough. It was find out that maximal load corresponding to almost 70 % of the maximal load of the backpressure turbine is sufficient. The steam production with standard steam parameters providing sufficient reliability without corrosion risk at pressure of 4 MPa and 400 °C is considered (Villani and Greef (2010)).

3. Technical Economic Model and Optimization Problem

The model of the plant and parameters of fuels are described in detail in (Touš et al. 2010). Briefly, the model consists in modelling of boilers and turbines via regression functions transforming calorific value of fuels into heat and electricity. The model of the plant is built using operation data. The model of the WTE plant is designed as a boiler with turbine and the WTE plant is interconnected with the heating plant only via cooperation on meeting heat and electricity demand on a month's basis. Expected demand throughout the year is based on historical data (see Fig. 2). The boiler capacity is derived from annual amount of MSW processed (annual capacity). The regression functions transforming calorific value of MSW into heat and electricity are evaluated using in-house built software tool W2E described and used in works by Pavlas et al. (2010) and Touš et al. (2009).

When the technical model is designed and built, economic parameters may be added. There are many factors influencing economy of the process. Typically, these are fuel prices, heat and electricity price and possibly a bonus on cogeneration according to EU legislation. Considering the biomass utilization in the heating plant, there may be subsidies for renewable energy sources utilization. Considering WTE plant, the economy is assessed in a different way because it is new, not existing, plant. The important economic factor, besides incomes from heat and electricity export, is gate fee. Income is compared with annualized capital and operating costs. Operating costs consists of maintenance which dependents on designed annual capacity of the WTE

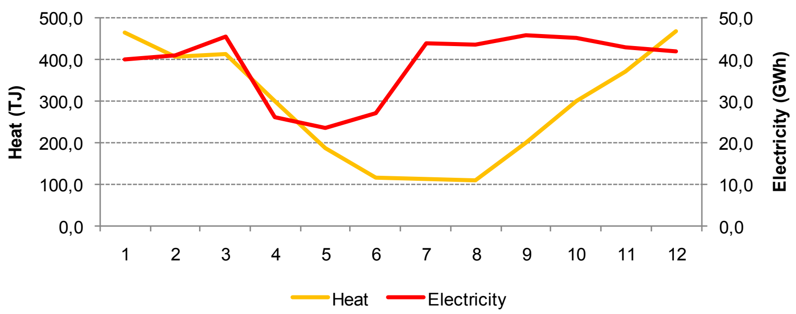

Figure 2: Heat and electricity demand throughout the year

plant (assessed as percentage of capital costs). Then there are costs of residues disposal and waste processing (chemical substances) which dependents on actual amount of waste processed. Costs of transport are dependent on radius of waste collection area (circle shape is assumed). The amount of waste collected from this area should correspond to annual capacity of WTE plant. Many of the WTE related parameters and costs are based on practical experience of one of the authors with WTE plant design. As far as MSW is concerned, its estimated calorific value is 10.6 GJ/t (estimation based on data of a real WTE plant).
The model is used for evaluating fundamental design parameters of WTE and optimal operation of the integrated system with maximum annual profit of the system (time step of one month). It is implemented in GAMS optimisation system. GAMS is algebraic modelling language and is widely used for optimisation problems in the field of energy systems (for more information on optimization packages and software used see work by Lam et al. (2010)). The optimization problem is solved using BARON (Branch-And-Reduce Optimization Navigator), which can be applied for global optimization of nonlinear programming problems.

4. Fundamental Design Parameters of WTE and Operation Planning

First of all, the designed annual capacity of the WTE plant is analysed. The feasibility of WTE plant integration is dependent on gate fee because income from waste processing is the main income (others are from electricity and heat). For gate fee up to 72 €/t and other current prices, the new WTE project is not economically feasible. Annual profit of the integrated system is lower than annual profit of heating plant alone. Then there is step change and for gate fee higher than 72 €/t WTE plant with annual capacity of 147 kt/y is proposed. This corresponds to boiler with capacity of 50 MW and steam production of 53 t/h. The corresponding collection area has radius of 36.7 km. Now, the objective is to find optimum operation of the integrated system with maximum annual profit. Since the MSW is very beneficial as a fuel with negative price (due to the gate fee) the full operation of the WTE plant is expected. The WTE plant cogeneration system provides the flexibility in terms of electricity and/or heat

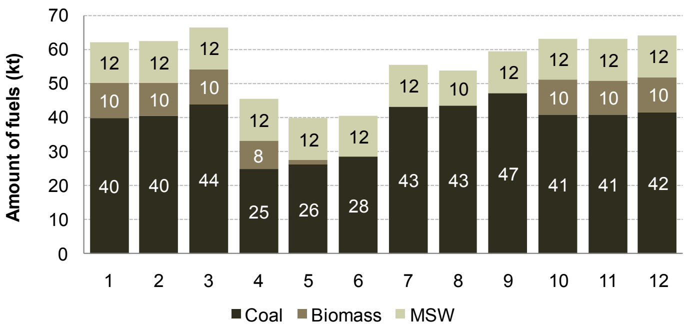

Figure 3.: Coal, biomass and MSW utilization throughout the year

production.

Heat delivered from WTE plant influences the operation of every boiler of heating plant as well as turbine. The task is to predict the energy flows through all these key components (boilers, turbines) included in the overall model. The Fig. 3 shows fuels utilization throughout the year. The only exception in operation of WTE plant at full load is in August, when WTE plant has to decrease its load. The heating plant is at its minimum load and both the heating plant and WTE plant are in full condensing mode (maximum electricity production). Even though heat demand is too low to enable maximum load of WTE plant the decrease in load of WTE plant is acceptable. But primary objective of WTE plant is waste processing and more significant decrease could mean unacceptable accumulation of MSW.

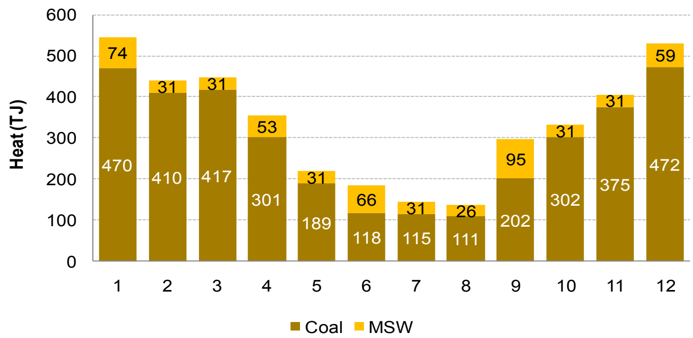

Figure 4: Heat production throughout the year

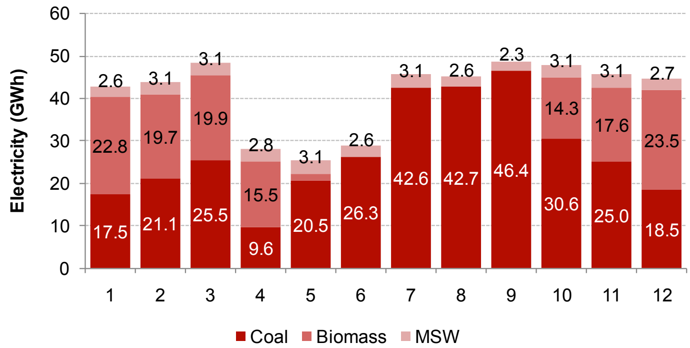

Figure 5: Electricity production throughout the year

As far as utilization of fuels in heating plant is concerned, biomass is preferred in colder months due to calculation of electricity production from renewable energy sources (RES-E) when co-fired with coal. RES-E is subsidized and the amount calculated is dependent on heat production (this is described in more details in work by Touš et al. (2010)). This is also reason why WTE plant is preferred for electricity production. WTE plant is in maximum condensing mode (31 TJ of heat and 3.1 GWh of electricity) for six months (see Fig. 4 and Fig. 5), especially the colder ones. The exceptions are

January, April and December. In these months the heating plant cannot satisfy the heat demand.
It is important to emphasize that the results are very sensitive to parameters related to turbine house of WTE plant. WTE plant with higher annual capacity is proposed for increased capacity of condensing turbine because it improves flexibility of operation planning.

5. Conclusion

The paper presents the evaluation of feasible integration of WTE plant into existing energy producing system – the heating plant. It is briefly outlined how the problem can be solved and the approach is demonstrated on the case study. The solution is based on results from previous work by Touš et al. (2010). First, the essential parameters of the WTE plant are evaluated. Then the optimal operation plan is proposed based on maximization of annual profit.

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