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# Energy conception of an integrated system – I. Analysis of available data and its processing

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Fossil fuels such as coal and natural gas dominate in current energy production plants. However, their burning is evidently characterized by large carbon footprint. This fact combined with the observable trend of rising prices of fossil fuels, their unclear future availability together with the afore mentioned negative impact on the environment increases the interests in renewable and alternative fuels. This paper describes a methodology of integration of perspective biomass-based solid fuel into complex systems supplying heat and/or power. Modification of the approach used for industrial and municipal sector as well as the difference between new design and retrofit of an existing system are mentioned. The need for tackling several problems (fuel availability, environmental legislation, limited funds) is emphasized. The procedure is demonstrated through real industrial case study.

## 1. Introduction

Fossil fuels prevail in primary energy consumption worldwide. If we focus on the European region consumption of primary energy in the form of coal/lignite and natural gas was 320 and 445 Mtoe, respectively. Energy-related emissions produced by utilities during combustion of these fuels reached more than 4000 Mt of CO2. Issue of optimization of energy producing systems focused on increase of overall efficiency and effectiveness together with reduction of carbon footprint was analyzed many times. Some of the researches published recently will be discussed later. The optimization task regarding utility system involves the following types of specific problems:

- Grassroot design
- Retrofit
- Operational problem

Due to the nature and characteristic features of the systems the task needs to be differentiated as follows:

- Industrial field
- Municipal sector

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Demands on hot and cold utilities within large industrial plants are in relation with production rate of desired product, change of raw materials, change of quality, etc. This amount of supplied/rejected heat is not significantly dependent on climatic conditions. Task is usually handled using particular average operational conditions. If it is necessary, two scenarios are involved (e.g. one for winter season and the other for summer operations). Heating of cold process streams up to their target temperatures takes place on different temperature levels. The waste heat rejected from hot process streams is available at several temperature levels as well. Thanks to this fact large industrial processes are very good candidates for complex optimization.

One of the most successful systematic approaches, which are applied in a number of modifications in different industrial fields, is a process integration methodology, especially an approach based on Heat Recovery Pinch. It provides us with tools allowing investigation of heat fluxes within the process and determination of maximal waste heat utilization and therefore it enables minimization of demand on external utilities. This methodology can be applied on a single plant as well as on a set of plants situated on one site. In this case we may speak about Total site integration (Klemes et al., 1997). The most commonly used hot utility in industrial sector is represented by steam of different parameters (very high, high and low pressure steam based on the requirements). The optimization task in this case indicates the number and location (as far as temperature in grand composite curve diagram is concerned) of steam mains with the major aim to maximize power generation by steam expansion on turbines installed between two mains working at different pressure levels (Varbanov et al., 2005).

Industrial utilities represent a complex system. It has to provide required service even if any component is in outage. Thus Aguilar et al. (2008) propose an optimization framework enabling to find reliable solution for different scenarios (i.e. not only an average operational condition is taken into account). It is called a multiperiod optimization framework where availability and reliability represent some of the key factors which have to be respected during design phase.

In addition to low annual costs, optimally designed system contributes to environment protection. Aguilar et al. (2008) have pointed out that increase in efficiency of the system is the best and most economical way of reducing CO2 emissions. On the other hand though the potential is limited. Other possibility of significant carbon footprint reduction is a utilization of renewable sources of energy. Integration of renewables within enlarged geographical area has been studied by Perry et al. (2008). He uses total sites profiles for infrastructure including hospitals, small enterprises, distributive cogeneration systems, etc. It has been solved as a single period task. Due to its character the infrastructure of this kind is subject to demand variations. However, this has not been considered. In contrast with industrial field, heat consumption in municipal sector changes according to seasonal residential heating requirements and thus the so called multi-period task is concerned. Since the system of this kind is the scope of a real industrial case study presented here, the details will be discussed later on.

## 2. Real integrated system

An example of integrated system design for real heating plant is presented in the following text. Heating plant satisfies two thirds of the demand for heat and cold in a city of nearly 200 thousand inhabitants. Power is produced simultaneously. The plant secures delivery of heat to residential areas, public institutions, regional hospital as well as to industrial enterprises (e.g. a brewery).

From the historical point of view the plant was being extended in several periods up to a current state. Today's installed capacity equals to 461 MWth a 137 MWel. An overview of key components (boilers and turbines) is depicted in table 1.

*Table. 1: List of key components*

| Boiler room I | Boiler room II | Boiler room III | Turbine room | |
|---|---|---|---|---|
| 2 hot-water boilers with capacity 35 MWth | 2 granulation powder steam boilers with capacity of 128 MWth | 1 fluidized bed steam boiler with capacity of 135 MW | 1 back-pressure turbine 70 MWel | 1 condensation extraction turbine 67 MWel |

In 2007 the plant delivered 3437 TJ of heat to its customers. At the same time 455 GWh of electricity was dispatched to the national grid. The overall energy balance of the enterprise is shown in fig. 1. In the fuel basis, lignite (annual consumption approx. 600 kt) dominates. Regarding a reduction of CO2 emissions biomass is a considerable fuel. It is combusted in boilers erected in periods II and III. Its share on the overall is growing annually thanks to successive resolution of operational problems (improvement adjustment of transport and logistic routes). In 2007, 60 kt of biomass was processed (7 % of fuel input). In 2008 the numbers were at 100 kt.

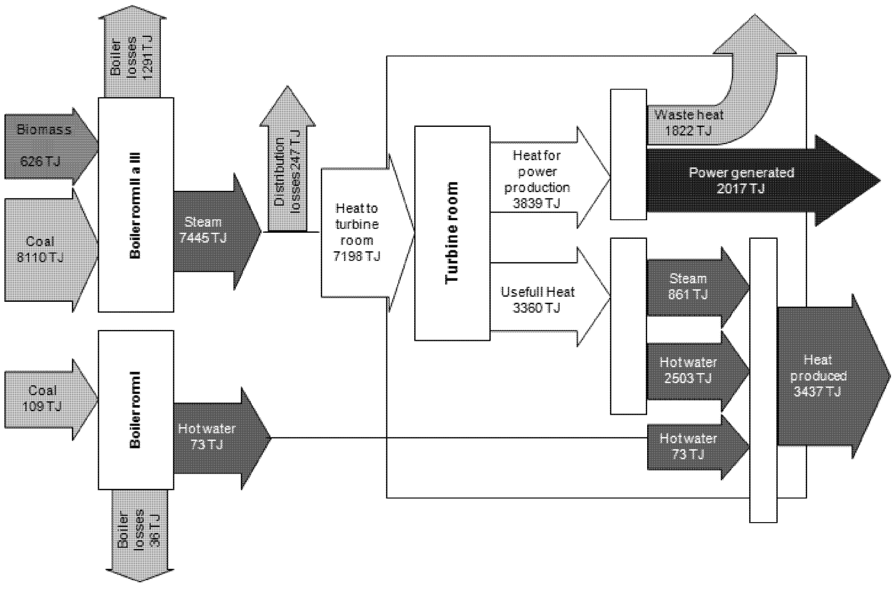



*Fig. 1: Overall energy balance for the plant (year 2007)*

Taking into account observable trend of increasing fossil fuel prices, unclear fossil fuel availability for the future in the region, the management of the plant will follow the trend of substitution of fossil fuels with renewables in the future. Boiler room IV with one 35 MWth steam boiler entirely fired by biomass is going to be put into operation in near future. The produced steam will be utilized in a newly built extraction condensing turbine of 10.3 MWel. The consumption of biomass (mainly wood chips and bark) will increase thanks to a boiler newly put into operation. In combination with the limited regional resources of biomass-based fuels at an acceptable price this expansion requires implementation of a complex approach focusing on solving the following tasks:

- Systematic planning of co-combustion of remaining biomass in existing boilers built in periods II and III to provide the highest efficiency and profitability of the cogeneration process
- Sustainable supply of other biomass-based and alternative fuels for coal share reduction and analysis of accompanying investments.

According to the classification of optimization tasks published by Salgado and Pedrero, (2008), the first mentioned task fits into framework of the so called Mid-term horizon optimization. Structure of the system is given (number of units and their capacities), thus we are concerned with the pure operational issue. Time period is selected at maximum one year (in multiperiod task a year is divided into shorter intervals, such as months, etc.). Investments are usually not included or they are not enormous (since the structure of key component is fixed, these are related only to auxiliary equipment, e.g. adjustment of feeding system) and we expect a short payback period, i.e. within few years). Techno-economic analysis is performed in order to analyze benefits of increased share of the combusted biomass (De and Assadi, 2009), optimization of its distribution between boilers, determination of acceptable price of renewable fuels, effect of decreased overall efficiency due to increased power production, etc.
The other optimization task mentioned above refers to Longterm horizons. It forms the frame and rules for future development of the utility system. Large investments are inevitable and longer payback period is expected. Erection of new units like municipal solid waste incinerator with integrated heat utilization and highly efficient blocks producing green power represent concrete examples of these activities. Future investment projects related to our case study are as follows:

- Alternative fuel pretreatment centre where different biomass-based feedstock is processed (crushing, drying, peletization, etc.) to produce valuable fuel. Potential feedstock is summarized in table 2.
- Installation of off-gas cleaning system enabling co-combustion of sewage sludge and refuse-derived fuels with the lowest impact on the environment
- New waste-to-energy unit for incineration of municipal solid waste.

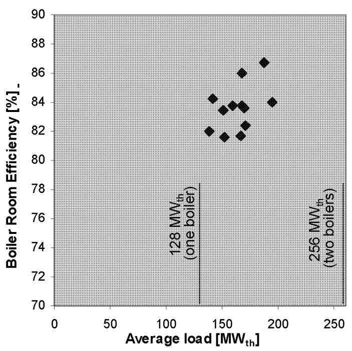
An optimization procedure has been proposed in order to support energy producing systems where fossil fuels are effectively substituted with renewable and alternative fuels. It is described in detail in Popela et al. (2009). In the following part of this paper certain aspects related to the methodology based on a highly elaborate approach are discussed.

*Table. 2: Locally available u-traditional biomass-based feedstocks*

| | Available amount [t/y] | Dry matter [% mass] | Ash [% mass] | LHV [GJ/t] | Remarks |
|---|---|---|---|---|---|
| **Spent grain** | 90 000 | 20 | 1 | 2,1 | Wet material/ biodegradable |
| **Sugar beet pulp** | 45 000 | 88 | 11 | 13,1 | Dried |
| **Paper mill sludge** | 6 000 | 23 | 3 | 2,5 | Wet material |
| **Sewage sludge** | 15 000 | 25 | 14 | 0,36 | Wet material Heavy metals |

## 3. Performance data

Mathematical model description of all key components of the system is essential for a development of any optimization approach in the field of utilities. Fuel energy is transformed into steam in a boiler. Steam is further led into turbine where it expands and produces power. Steam is then utilized for the purposes of heat production (in case of a backpressure turbine) or it is rejected into the environment through cold utilities (condensing turbine). Boiler efficiency and power generation efficiency in turbine represent key transformation functions. The simplest approach found in technical literature is based on constant efficiencies. More complex models also include variation of performance with part-load (in the forms of performances lines or curves, see fig. 2).




*Note: Boiler room II consists of two 128 MWth boilers*

*Fig. 2: Real performance area for Boiler room II derived from historical data*

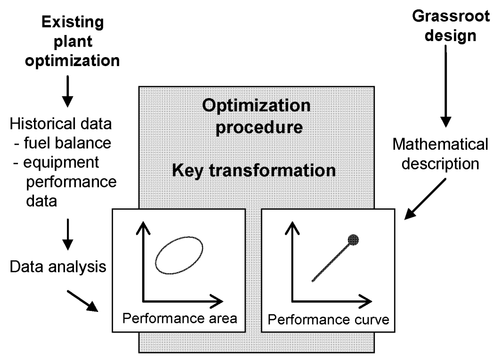



*Fig. 3: Two approaches for key transforation description*

Following industrial practice, efficiency of real systems is not dependent only on actual load but also on number of other parameters which are hard to describe for the purposes of modeling. This is illustrated in fig. 3 for Boiler room II where two boilers with nominal capacity of 128 MWth are installed. The available balance data related to this part of process were analyzed. Final "performance area" is depicted in fig. 2. Similar approach can be applied to turbines and other key components. The optimization approach designed by Popela et al. (2009) for solving both afore mentioned tasks (i.e. pure operational issue and grassroot design in terms of technology extension with new units) has to be capable of tackling both performance description derived from available past operation data on one hand and theoretical performance model on the other. This is illustrated in Fig. 3.

## 4. Conclusion

The paper focuses on substitution of fossil fuels with renewables in real heating plant with installed capacity of around 500 MWth. Atypical biomass-based alternative fuels (e.g. spent grain, sugar beet pulp, sewage sludge) are available locally. Different strategies for future sustainable development involving these fuels were specified for the plant. To evaluate these strategies and secure effectively running plant a sophisticated approach is necessary. The framework for optimization procedure has been proposed in a practical way.

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