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Analysis of wood fuel CHP operational experience

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Abstract

The subject of the research in this article is the analysis of operational modes of a wood chip-powered cogeneration plant in terms of fuel consumption. The data set for analysis comprises the data measured on an hourly basis at the cogeneration plant. The volume of the data set is 720 modes. It can be observed that the specific fuel consumption increases along with a part of the condensation modes (α value increases). The correlation analysis of data has been carried out, and an equation linking the specific fuel consumption to the changes in the ratio of power generation to heat energy has been obtained. The average value of the specific fuel consumption of the plant's cogeneration mode is 1.19 ± 0.1 loose m^3/MWh and power-to-heat ratio is 0.48 ± 0.03. The uncertainty in the average measurement is defined for a 95% confidence interval. Along with the increase in the power-to-heat ratio value by 0.1, the increase in the specific fuel consumption is 0.19 loose m^3/MWh.

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Keywords: specific fuel consumption; cogeneration plant; power and heat generation efficiency; power to heat ratio

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1. Introduction

The efforts of European Union Member States to reduce impact on climate change have gone in two directions. The first is in increasing the proportion of renewable energy resources by substituting fossil fuels with bioenergy, geothermal, solar, and wind energy. The second direction is related to increasing the energy efficiency of energy sources, energy supply networks and on the consumer side. The climate policy of the European Union comprises objectives on reducing greenhouse gas emissions for 2020–2030 for each Member State [1] and all the Member States together.

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An important role in the implementation of the climate policy is played by biomass, the energy-efficient use of which is possible due to longstanding traditions in technological development and in economically justified biofuel expenses. Biomass can be of different types, from wood and straw to organic waste. It is distinguished by combustion heat values, the range of application, specific nature of operation and by the end product which is obtained from biomass. Biomass can be used to produce biogas, syngas, heat energy and electrical energy. The most often used type of biomass from which the energy of the highest quality is produced, namely electrical energy, is energy-efficiently used wood. The price of natural gas and oil products are two to four times greater than the expense of one energy unit of energy-efficient wood.

The wide range of technologies for biomass applications includes furnaces, boilers, cogeneration plants with different cycles, as well as technological solutions for electrical energy production. Each unit of the equipment has its own scope of application, coefficient of efficiency and operational specifics.

The aforementioned form a good precondition for the energy-efficient use of wood, producing heat energy and electrical energy at the same time [2]. Innovative and energy-efficient wood fuel combined heat and power generation plants (CHP) may be characterised by high power generated -to- heat energy ratio $\alpha > 0.4$ and low operational and maintenance costs. An important role is played by capital investments. When compared to the range of specific investments of biomass cogeneration plants located in Latvia (summarised and mathematically processed information from the Procurement Supervision Bureau of Latvia) with the information available in different scientific studies, it can be seen that the specific investments in biomass cogeneration plants located in Latvia are within the limits of the examined studies (see Fig. 1). The blue columns show the range of dates of studies, while yellow columns show the information of the Procurement Supervision Bureau.

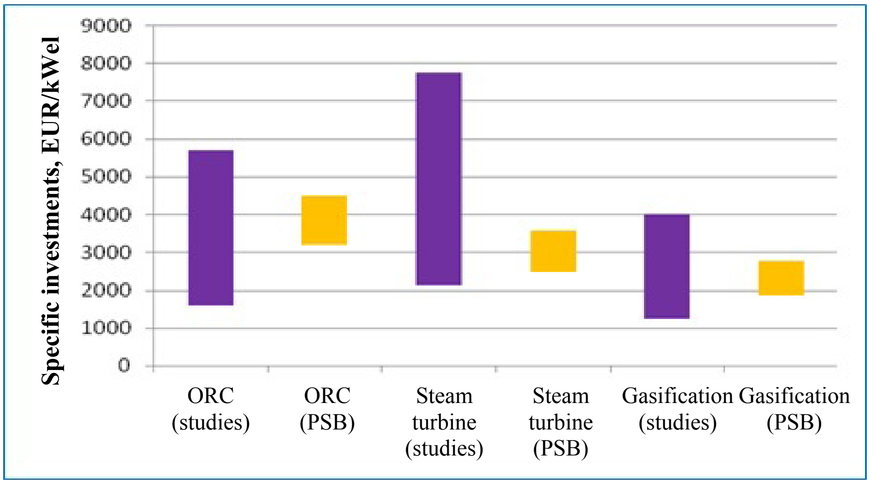

Fig.1. Comparison of ranges of specific investments depending on technological solution.

The research literature review traces a wide range of issues related to the use of biomass, including the uses of different types of biomass, economic and thermo-economic aspects of biomass usage, properties of co-burning, emission levels of gases and solid particles, as well as operational factors that influence consumption. The efficiency of cogeneration plants can be described by a specific fuel consumption rate, which is determined by relating the amount of fuel with the amount of generated energy. All the reviewed studies distinguish the dependency of the obtained data on a specific mode of operation. The type of plant's operation is determined by the demand for heat energy and electrical energy, which are interconnected – the heat load determines the possible generation of electricity. However, under the electricity market liberalisation, its price is time-variable and it creates an economically favourable offer for the plant [3], if the plant is able to operate dynamically with the variable generation of electrical energy. If the creation of the plant does not provide for dynamic operation, it will work in partial condensation modes by following the demand for electrical energy. It is necessary to analyse how technically and economically favourable partial condensation modes are and what parameters determine their favourability. The article analyses one of the influencing factors – the specific fuel consumption and its changes.

2. Research Method

The object of research of the article is the analysis of operation modes of a wood chip-powered cogeneration plant in terms of fuel consumption. The basic equipment of the cogeneration plant (CHP) is the fluidised-bed steam boiler (Q_b^n = 75 MW; generated steam pressure P1 = 1.15 MPa; preheated steam temperature t1 = 520 °C), back-pressure steam turbine with two steam extractions for water heating in the first stage DH1 and second stage DH2 network water heaters, as well as a power generator (N_{el}^n = 25 MW). At the plant, a flue gas condenser, which is not shown in the schematic diagram of the equipment connections, Fig. 2, is installed behind the boiler. The heat recovered in the condenser is used partially to cover the heat consumption.

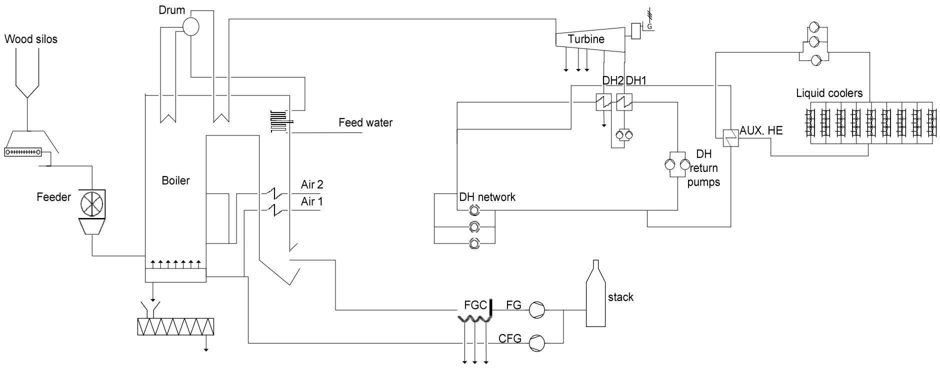

Fig. 2. Schematic diagram of the cogeneration plant for operation in the cogeneration or partial condensation modes. Modes are determined by heat load (Q_{th}), electrical load (N_{el}), and network water cooling (Q_{lq}) load.

The cogeneration plant produces electrical power by generator of a turbine, which is then fed into a network, and the heat energy is then used for the heating supply. The chips are burnt in a fluidised bed furnace of a steam boiler with a double air supply, generating overheated steam. The steam is used in a back-pressure turbine. An important role is played by users of the heating system, who consume low-potential heat. The steam from the turbine and the low-pressure outlet is then used for preparing water in the two-step network water heaters.

The nominal heat load of the cogeneration plant Q_{th}^n is 50 MW. The studied cogeneration plant may operate in the cogeneration mode, in which the generation of electrical energy corresponds to the heat generation in a proportion typical for the equipment (α value), or in the partial condensation mode, during which the required heat load is less than that determined by α value. The difference between the possible load of the plant and the load required by the consumer is absorbed by the network water cooling equipment (liquid cooling) installed at the plant. This part of the heat represents heat losses. The research [4] shows that the distribution of the heat produced by the cogeneration plant between the heat supplied to consumers (Q_{th}) and the heat lost at the plant (Q_{lq}) significantly affects the fuel consumption. The electricity produced at the plant in proportion to the consumer's heat load is the cogeneration electricity, whereas the remaining energy is produced in condensation mode. The parameter which characterises the cogeneration and partial condensation operation is α value. In partial condensation mode, the plant works with α value which is higher than the value of installed technologies operating with the nominal parameters.

The data set for analysis comprises the data measured on an hourly basis at the cogeneration plant during the time period from 4 December 2013 to 23 January 2014. The volume of the data set is 720 modes.

The variables that were measured and used for analysis are as follows:

- Fuel consumption B, loose m^3/h;
- Heat load Q_{th}, MW;
- Electrical capacity N_{el}, MW;
- Network water cooling capacity Q_{lq}, MW.

The relative variables describing the plant were identified on the basis of measured data:

1. The ratio of electrical capacity to consumer's heat power typical for technologies of the cogeneration plant (power-to-heat ratio)

$$\alpha = \frac{N_{el}^{n}}{Q_{th}^{n}} = \frac{25}{50} = 0.5 \tag{1}$$

2. The ratio of electrical capacity to consumer's heat power of the cogeneration plant modes

$$\alpha = \frac{N_{el}}{Q_{th}} \tag{2}$$

3. Specific fuel consumption of the plant

$$b_{ch} = \frac{B}{Q_{th} + N_{el}}, \frac{loose\_m^3}{MWh} \tag{3}$$

By using α values from the set of measured data, cogeneration ($\alpha \approx 0.5$) and condensation ($\alpha > 0.5$) modes are distinguished. In the present study, for the purpose of analysis of the operation of the plant, the correlation between the variable b_{ch} and independent variables α value is analysed. By means of a correlation analysis, the mutual link and its strength between two variables determined. The results of the analysis are presented in the next section.

3. Analysis of Research Results

The changes in the α value of the ratio of the specific fuel consumption and electrical energy to heat energy in the cogeneration modes of the plant, as illustrated in Fig. 3 with minor fluctuations along the average values of measurements.

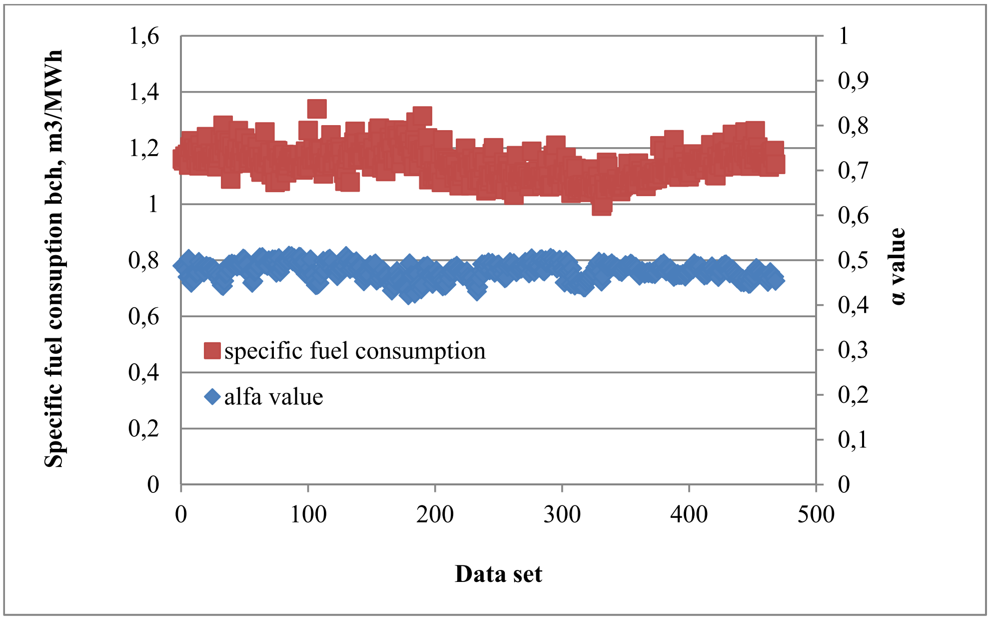

Fig.3. Changes in the average specific fuel consumption of the cogeneration plant (higher graph represented on left-hand axes) and the α value (lower graph represented on right-hand axes) in cogeneration mode within the period from October 2013 to January 2014.

The value of the average specific fuel consumption of the period is 1.19 ± 0.1 and α value is 0.48 ± 0.03. The uncertainty in average measurements is defined for a 95 % confidence interval. By assessing the relative values of uncertainty in average measurements, they are ± 8.4 % for fuel consumption and ± 6.2 % for alpha value. The greater relative uncertainty for the specific fuel consumption is explained by the difficulties in determining the wood chip consumption. Heat and electrical power measurements are more precise.

In order to determine and compare the specific fuel consumption in cogeneration and partial condensation modes of the plant, the schedule presented in Fig. 4 has been developed. The volume which characterises the modes is α value which is greater by 0.5 in the partial condensation modes.

It can be observed that the specific fuel consumption increases along with a part of condensation modes (α values increase). The correlation analysis of the data has been carried out, and an equation linking the specific fuel consumption to the changes in the ratio of the produced energy to heat energy has been obtained. Along with the increase of alpha value by 0.1, the increase in the specific fuel consumption is 0.19 loose m^3/MWh. Due to the significant dispersion of data, the square value of the correlation ratio is low.

The changes in the ratio of the produced electricity to heat energy are related to increase in the power generation in comparison to the heat energy generation. At the cogeneration plant, the production of electricity has lower energy efficiency if compared to the production of heat energy. Therefore, an increase in the electrical energy production reduces the total energy efficiency; as a result, fuel consumption increases. It can be seen that the cogeneration plant is a technical compromise solution between the production of electricity and heat energy. Therefore, the use of the cogeneration plant solely for the production of electricity is less efficient than carrying out the production of electricity at the condensation plant.

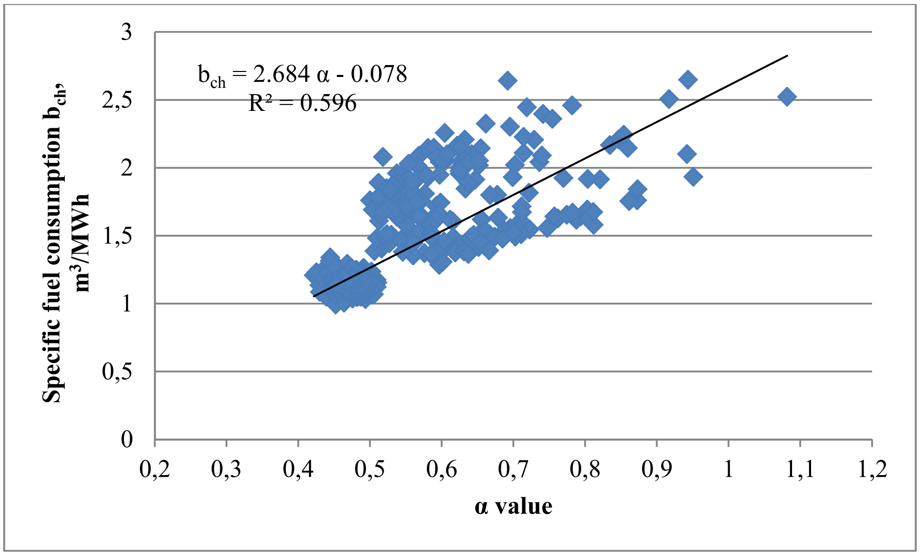

Fig. 4. Changes in the hourly average specific fuel consumption of the cogeneration plant in the cogeneration and partial condensation modes depending on the value of the ratio of the produced electrical energy to heat energy.

Power generation in CHP in cogeneration mode depends on heat load. However, another viewpoint is that it is possibility to guarantee more flexible power generation. Back-pressure turbines in CHP in cogeneration mode require fixed ratio between electricity and heat production. Sometimes electricity production is economically feasible, but heat demand remains at the same level. In this case, excess heat goes to the cooling equipment of CHP (see Figure 2). This is wasted heat and could be defined as heat energy produced in condensing mode. This means that CHP partly operates in condensing mode. The operation of the cogeneration plant in condensing regimes may be increased in partial condensation modes by producing electricity on the basis of condensation heat [5]. Such circumstances require the installation of a heat accumulator at the plant for accumulating heat during the increased production of electricity [6] and supply the heat energy in cases of reduced requirements of electricity. This win-win situation allows to reduce the amount of wasted heat and to increase efficiency of produced heat energy through the use of the accumulation system.

4. Conclusions

When comparing the cogeneration plant's energy-generation processes, it can be observed that the highest rate of efficiency is in the cogeneration mode, if compared to the partial condensation modes. This situation can be explained by losses in the energy generation processes, which are higher in the case of power generation than in heat generation for consumer needs. The reduction of specific fuel consumption rate is determined by possibilities of loss reduction within plant's energy generating processes.

Another way is to install a heat accumulator at the plant, which allows for the production of heat and for its accumulation in case of high electrical energy generation, thus ensuring the operation of the plant in a more efficient partial condensation mode.

The research carried out shows that when transferring from cogeneration modes to partial condensation modes, the specific fuel consumption at the cogeneration plant increases. Along with the increase of the alpha value by 0.1, the increase in the specific fuel consumption is 0.19 loose m^3/MWh.

Acknowledgements

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