METHODS OF INCREASING THE EFFICIENCY OF COGENERATION BASED ENERGY EQUIPMENT

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The evaluation of the performance characteristics of the device has a many type, depending on the monitored parameters. In the field of continuous measurements there is a quantum of measurement systems that allow long-term tracking and feedback. Part of the submitted contribution concerns the creation of a cogeneration unit model to monitor the flue gas pathways in relation to the production of pollutants in a non-destructive method. In the case of non-destructive monitoring and interventions in the objects, the use of the virtual laboratories. Such laboratories represent a computer-generated virtual environment in which a model of a particular device is created and a simulation of specific aspects of the matter. The priority given in this paper focuses on the correctness of the operation of the existing system in the case of integration of an external device into the existing flue path and the subsequent analysis of the influence of the further course of the flue gas particles.

KEYWORDS

Efficiency, cogeneration, ansys, simulation, energy

1 INTRODUCTION

The integration of new energy sources and renewable energy-based systems is becoming more useful in modern technology. Cogeneration systems from the point of view of energy production are becoming a more significant part of modern alternative sources. The elaborated paper describes a particular installed cogeneration unit. The functionality of a dismantled cogeneration unit consists of a diesel engine driving an asynchronous generator connected from a heat exchanger system. [Rimar 2018] Integrating renewable energy sources and a cogeneration system on the basis of Act No. 309/2009 Coll. becomes an important part of energy production. The implementation of Directive 2004/8 / EC of the European Parliament and of the Council is an essential element of the development of the internal energy market. [Act No. 309/2009] [Directive 2004/8/EC]. The proposed cogeneration systems are optimized according to economic and energy requirements with respect to environmental criteria. [Rimar 2018]. The main idea of installing cogeneration units is to reduce the cost of primary energy, reduce pollution and increase efficiency by integrating renewable energy sources. [Rajniak 1997] [Mackay 2009] The evaluation of the performance characteristics of the device has a number of types, depending on the parameters monitored. Most importantly in the cogeneration operation is the monitoring of the parameters of the cogeneration unit itself. These are typically monitored by an autonomous control system that enables online access to data measurement. However, the measurements are aimed at maintaining the required output power quantities. The measurement of combustion products is carried out using the same methodology as for conventional heat sources. In practice, discrete methods of measurement are used to assess compliance with legislative limits. [Act No. 309/2009] [Directive 2004/8/EC] In the field of process optimization, continuous measurements are used, allowing for the observation of long periods of time and their retrospective evaluation. However, the use of such a measurement method is difficult in terms of comparing measurements, as it often does not allow measurement on multiple devices at the same time. One option is to use the so- virtual laboratories. These laboratories represent a computer-generated virtual environment in which a particular device model is created. In these cases, it is possible to track various input, output and operating variables at the desired time increments. A variety of simulation tools such as ANSYS are used to create a virtual lab. Part of the submitted contribution concerns the creation of a cogeneration unit model to monitor the flue gas pathways in relation to the production of pollutants, not only to the facility but also to the surroundings of the installation. The simulation allows you to vary input and operating conditions, install various components such as heat exchangers, coolers, heaters, turbochargers and other devices and monitor their impact on a particular improvement of an existing system. In this way, it is possible to increase the efficiency of the power plant. Software ANSYS 19.0 was used for software simulation and presentation of computational analyses. Simulation software nowadays often provides a perfect model of the current technical aspect. [Tadeusz 2006]

2 MATERIALS AND METHODS

The issue addressed in this paper is aimed at demonstrating the operation of an integrated facility on the principle of CHP (Combined Heat and Power Production) in an existing system of CHS. The proposal represents an integrative link with the already existing system of central DHW preparation, heat and electricity supply. Virtualization of the device in the simulation environment is performed in relation to the interaction with the external environment. Compared to conventional methods of producing electricity, where the heat generated in the production of electricity is understood to be waste heat, the cogeneration unit thus produced by the waste heat permits the use of heating energy or heat for the preparation of DHW as a source of heat. [Krbek 1999] In contrast to the conventional power generation process, where the efficiency in the thermal power plants is about 30% or more. In steam-gas cycles where efficiency is reached at 50-60%, CHP technology enables the use of fuel energy with efficiency ranging from 80-90%. [Krbek 1999] In terms of flue gas production, the CHP contribution is assessed in relation to cumulated combined energy production. The monitored period represents the winter traffic represented by January and the summer operation in August for the years 2015 to 2018. The described cogeneration unit prepares hot water for approximately 1,600 dwellings, elementary school, kindergarten and shopping centers. The cogeneration unit itself consists of a gas combustion engine MWM / TCG 2016 V12C with a generator that provides 600kW of electrical and 650kW thermal rated output. In order to create the flue gas model, it is necessary to perform an analysis characterizing their qualitative parameters. One option is to perform short-term or long-term continuous measurements. The advantage of this method is to accurately determine the values. From the point of view of long-term evaluation, it is also possible to base the theoretical calculations on the assumption of perfect combustion of gaseous fuel. In this case, the methodology enables the equivalent theoretical quantities of flue gases and their individual components to be determined on the basis of a long-term assessment of the input fuel properties and volumes of its fuel consumption. As reported [Gursky 1981], Rosin and Fehling have found on the basis of experiments that burning physically and chemically very different fuels gives rise to flue gases whose composition is very poorly differentiated. Furthermore, it can be concluded that, based on their findings, there is a linear dependence between the amount of combustion produced and the fuel heat and air consumption. [Redr 1988] The theoretical methodology is sufficient to derive hypothetical quantities that will be produced in different operating modes. These values allow you to refine the input data used to define the proposed model. Due to the nature of the simulation tool, this allows simulation of the combustion process itself and on the basis of this, the flow of the flue itself and the amount of flue gas in the flue gas path. It is not necessary to carry out further measurements for their verification. One of the problems of this contribution was the solution of the evaluation of the products of the combustion process and the flue gas flow within the framework of the integration of the new exchanger system in the exhaust system. The algorithm for evaluating the combustion process is based on elemental fuel composition and flue gas analysis. [Varga 2013] [Gursky 1981] The volume of flue gas selected is determined on the basis of the following calculation:

$$V_{sp,min} = \frac{CO}{100} + \frac{H_2}{100} + 2 * \frac{H_2S}{100} + 3 * \frac{CH_4}{100} + 5 * \frac{C_2H_6}{100} + 7 * \frac{C_3H_8}{100} + 9 * \frac{C_4H_{10}}{100} + 4 * \frac{C_2H_4}{100} + K + \frac{CO_2^p}{100} + \frac{H_2O^p}{100} + \frac{N_2^p}{100} + 0{,}79 * L_{min}$$

$[m^3.m^{-3}]$ (1)

The process of perfect combustion can be expressed by the following combustion equations (2-5) which represent the elementary equations on which further numerical simulation processing takes place. [Varga 2013]

$$CH_4 + 2O_2 = CO_2 + 2H_2O + Q$$

$$1m^3CH_4 + 2m^3O_2 = 1m^3CO_2 + 2m^3H_2O \quad (2)$$

$$C_2H_6 + 3{,}5O_2 = 2CO_2 + 3H_2O + Q$$

$$1m^3C_2H_6 + 3{,}5m^3O_2 = 2m^3CO_2 + 3m^3H_2O \quad (3)$$

$$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O + Q$$

$$1m^3C_3H_8 + 5m^3O_2 = 3m^3CO_2 + 4m^3H_2O \quad (4)$$

$$C_4H_{10} + 6{,}5O_2 = 4CO_2 + 5H_2O + Q$$

$$1m^3C_4H_{10} + 6{,}5m^3O_2 = 4m^3CO_2 + 5m^3H_2O \quad (5)$$

Based on these conditions, a model of the solution was developed, which included the simulation of the course itself in the combustion chamber flue path.

3 ANALYSIS OF FUEL COMPOSITION, CALORIFIC VALUE, EXHAUST GASES

For the period under review, the fuel composition analyzes (monthly data with SPP) were processed in relation to the relative change in calorific value to fuel composition Fig. 1 and the production of flue gas (m^3) Fig. 2. [SPP 2019]

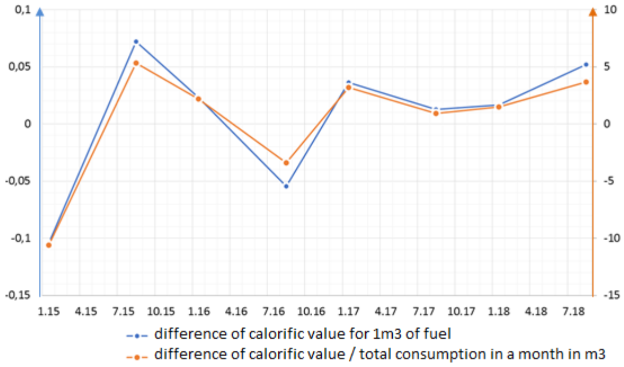

Figure 1 The effect of the relative change in fuel composition on fuel change over the reference period 2015 to 2018

Based on the analysis of the fuel composition of fig. 1 shows that the difference in fuel consumption over the monitored period represents a change in the range of 0.2kWh.m^{-3}. Concerning the equivalent monthly gas consumption in the given period, the given difference represents up to 15MWh of energy bound in the fuel.

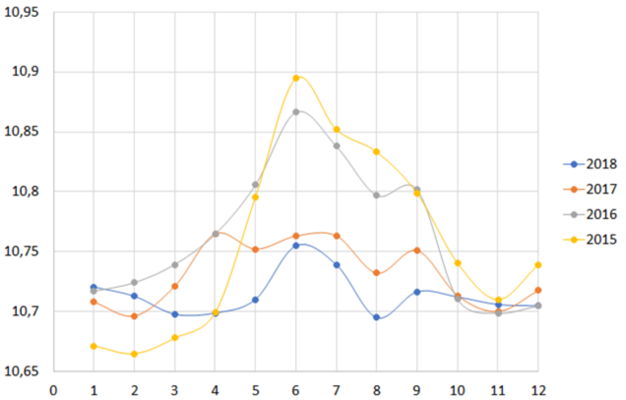

Figure 2 The impact of the relative change in fuel composition on the production of flue gas (m^3) over the reference period 2015-2018

The processes shown in Fig. 2 show a change in the course of the flue gas production (wet) depending on the composition of the fuel used. The comparison shows that this change is relatively close to the range of 10.66 - 10.89 m^3m^{-3}, but when calculating the absolute monthly fuel consumption, the resulting change of about ± 11500 m^3 of flue gas is compared to the average value of the flue gas produced. In tab. 1 shows the values of natural gas consumption and the calculated quantities of flue gas in m^3 for the period under review. Fig. 3 shows flue gas dependencies on fuel consumption in the monitored months of the 2015-2018 periods. From the course, it is possible to monitor the dispersion of values, which is directly proportional to changes in the composition of natural gas.

Table 1 Consumption values of natural gas, production of heat, electricity and flue gas for individual periods

	01/2015	01/2016	01/2017	01/2018
Consumption natural gas (m^3)	101680	94301	87339	89637
Wet exhaust gas (m^3)	1085059	1010620	935217	960954
Electricity production (MWh)	403.44	366.35	341.4	346.6
Heat production (MWh)	436.3	406.2	379.4	397.6
Heat from fuel cooling (MWh)	33.63	31.09	24.66	26.81
Σ produced heat (MWh)	469.93	437.29	404.06	424.41
Proportio produced heat from cogeneration unit on total heat production (%)	92.84	92.89	93.90	93.68
	08/2015	08/2016	08/2017	08/2018
Consumption natural gas (m^3)	75236	62009	74661	70978
Wet exhaust gas (m^3)	815050	669503	801268	759105
Electricity production (MWh)	294.83	239.4	288.6	272.3
Heat production (MWh)	330.8	269.1	331.2	315.7
Heat from fuel cooling (MWh)	25.6	21.72	22.9	19.84
Σ produced heat (MWh)	355.86	290.82	353.29	335.54
Proportio produced heat from cogeneration unit on total heat production (%)	92.96	92.53	93.75	94.09

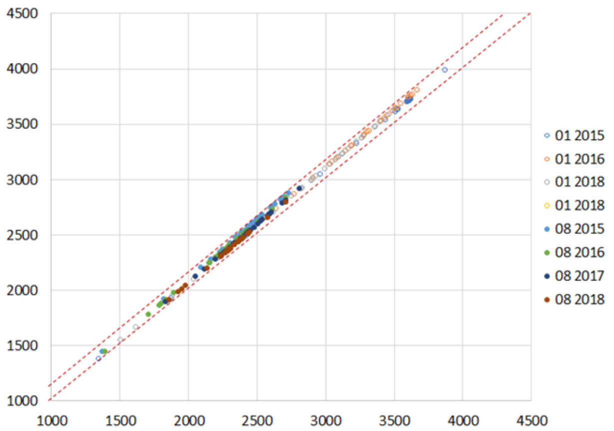

Figure 3 The course of the dependence of wet exhaust gases production on the consumption and composition of natural gas for the period 2015-2018

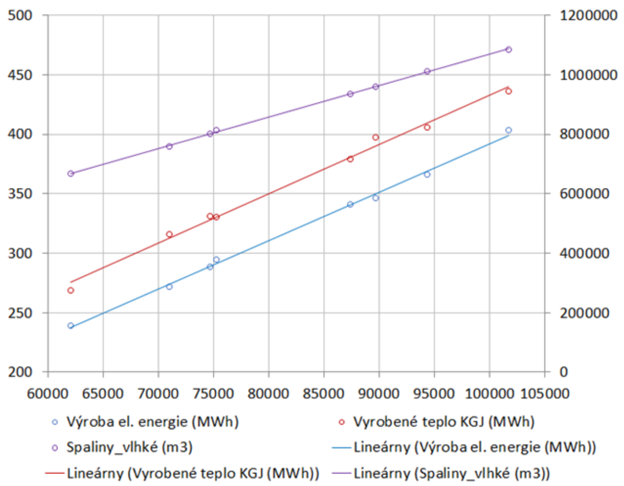

Figure 4 Dependence of produced electric and thermal energy and wet flue gas on consumption and composition of natural gas for the monitored period 2015-2018

The production of electricity and thermal energy compared to gas consumption is characterized by a significant correlation. Referring to fig. energy production curves are mutually parallel and point to a direct dependence on tied fuel in the fuel. The flue gas production process is less steep and has a direct relationship with the efficiency of CHP operation. At less power, the operation is less efficient, reflecting the more negative ratio of flue gas. This relative ratio improves with the increase in CHP performance and thus also with an increase in efficiency alone.

The observed deviations are attributed to fluctuations in the fuel composition, which are manifested as in the production of flue gas (Fig. 4) and in the production of electric energy itself and the corresponding thermal energy. [Varga 2013]

4 CREATING OF MODEL

The solution model itself consists of a series-installed new exchanger in the flue gas. The role of this exchanger is to increase the energy efficiency of the system as a whole. On the basis of the analysis described in the previous chapter, it is possible to determine the quantitative parameters of the flue gas, which serve as input data for the solved model. The average annual flue gas flow is converted to normal pressure conditions 1182.25m^3.hod^{-1}. The average flue gas temperature entering the flue path is 440°C. After the flue gas passes through the exchanger, their average temperature is about 200°C. The simulation solution evaluates the 440/120°C exchanger. The required theoretical flue gas temperature in the flue gas path should not fall below the temperature defined by the dew point of the flue gas. This means that the available heat gradient for further energy use is ΔT 80K Resp. ΔT 320K for tandem connection of exchanger. [Rajniak 1997] Average calorific capacity of combustion gas c_{s100K} = 1,377kJ.m^{-3}.K^{-1} c_{s200K} = 1,388kJ.m^{-3}.K^{-1},

$$Q_K = V_{sh} * c_{sp}^{s} * \left(t_{sp} - t_v\right) \text{ [kJ.h}^{-1}\text{]} \tag{6}$$

$$P_k = \frac{V_{sh} * c_{sp}^{s} * \left(t_{sp} - t_v\right)}{3600} \text{ [kW]} \tag{7}$$

V_{sh} – hourly amount of flue gas [m^3.h^{-1}]

t_{sp} – flue gas temperature entering the flue path [°C]

t_v – air temperature behind the exchanger [°C]

c^s_{sp} – mean specific heat capacity of flue gas [kJ.m^{-3}.°C^{-1}]

The theoretical output of flue gas for average values under specified conditions is Pk = 36,46kW. Subsequently, the theoretical daily gain is 875,18 kWh / day respectively. 27,13MWh / month. In terms of winter operation, the flue gas output is set at Pk = 41.37kW.

Subsequently, the theoretical daily gain in the given type of operation is 992.95 kWh / day respectively. 30,78MWh / month. The summer operation Pk = 31,56 kW, which represents 757,40 kWh / day and 23,48 MWh / month [Rimar 2013]

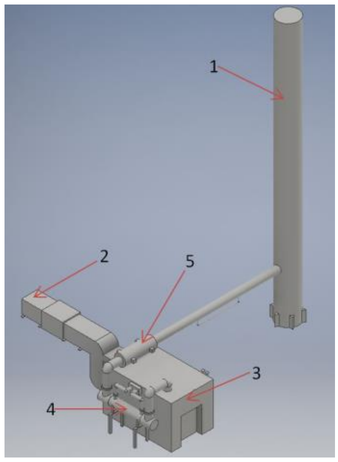

Figure 5 Cogeneration unit with flue gas

1- Chimney, 2-intake air, 3- container with cogeneration unit, 4- flue gas exchanger, 5- new exchanger

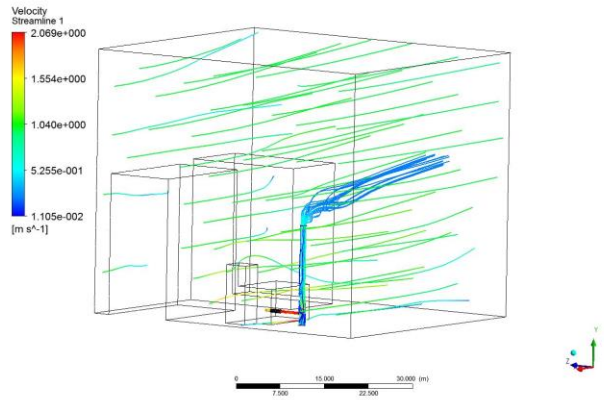

Figure 6 Simulation solution for the flue gas model

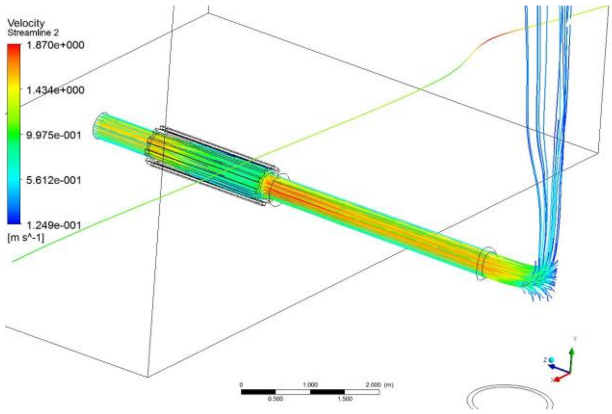

Figure 7 Simulation solution for the flue gas model

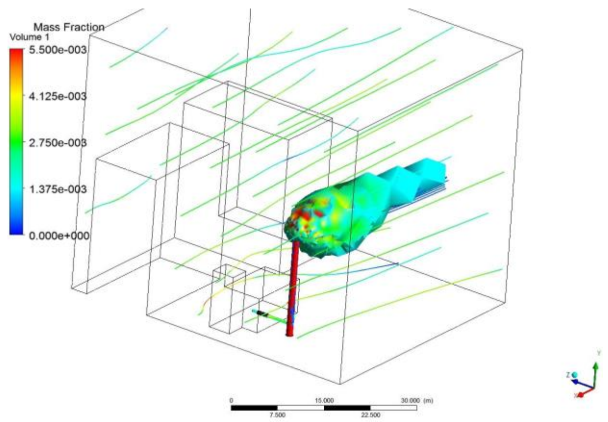

Figure 8 Simulation solution for the flue gas model

On the models shown, it is possible to see a very detailed course and monitoring of the flue path in relation to the production of pollutants. The created cogeneration unit model provides a detailed analysis and non-destructive way of presenting the flue track and its online monitoring based on mathematical calculations and virtual laboratory capabilities. Based on the results of the analyzes, it is possible to increase the efficiency of the installed cogeneration unit by integrating an external device in the flue path, which does not affect the further course of the process. The specific device in this case is the integration of the condensing exchanger before entering the chimney. A detailed analysis has been chosen for the annual interval 2015-2018, namely January. The dependence of the measured data is in the very fine range of approx. 2%, with a direct correlation with gas consumption and CO_2 production.

5 CONCLUSIONS

Based on simulations and theoretical calculations, it can be stated that it is possible to increase the efficiency of a cogeneration unit by installing an external device into the system. The comparison shows that for the selected heat gradient of 80K the theoretical energy gain is approximately 31MWh / month for winter operation, which represents an energy increase of about 7.6%. Summer operation enables an increase in the energy potential by an average of 23.5 MWh. This difference is due to the use of heat in the summer. The simulation model has confirmed the possibility of implementing a given solution for the placement of a more suitable exchanger in the flue gas. The results point to the preservation of sufficient kinetic properties of the flue gases even after crossing the obstacles formed by the design of the exchanger.

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