Preheating and Humidification of the Combustion Air to Increase the Hot Water Boiler Efficiency

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Abstract

Energy efficiency is one of the most pressing topics now. Energy consumption in-creases as living standards rise. Efficient heat production, i.e. efficient use of energy, is achieved with optimal boiler load. The second pressing issue is the protection of the environment from pollution. The process of burning different types of fuels to produce heat or energy results in emissions that can have negative impacts on the environment. One of the solutions to improve air quality is to reduce emissions from heating plants during their production.

The scientific paper considers the possibility of a preheating and humidification for combustion air system to increase the efficiency of the boiler and reduce the amount of harmful emissions in flue gases. The boiler efficiency values were calculated before and after the installation of the preheating and humidification system for the combustion air, and measurements of the flue gas analysis were carried out using a Testo 350 flue gas analyzer.

Calculations and measurements for flue gas analysis have shown that the combustion air preheating and humidification system increases the boiler house efficiency by 15 % and re-duces nitrogen oxide emissions by 70 %.

Keywords: combustion air preheating and humidifying, nitric oxide, enthalpy wheel, natural gas water boiler.

Introduction

The objective of this study is to investigate techniques for enhancing the efficiency of a hot water boiler and thus mitigating NOx emissions associated with thermal energy generation in a district heating (DH) system. With urbanization on the rise, it is projected that worldwide material consumption will more than double by 2060. Nowadays, the topic of energy efficiency is one of the pressings. Fossil fuels are one of the main non-renewable energy sources and are declining rapidly.

The burning of different fuels to generate heat or energy releases pollutants that can have detrimental effects on the environment. Among the primary harmful components of these flue gases are CO2 - carbon dioxide, NOx -nitrogen oxides, CO - carbon monoxide, PM - particulate matter SO2 - sulfur dioxide and other pollutants. The amount of emissions depends on the fuel type, combustion type, and whether or not technologies have been used to reduce emissions (Batrakov 2015; Bogatova et al., 2018; Shalaj et al., 2016).

Existing district heating (DH) networks will continue to be developed on the way towards the 4th generation district heating by decreasing heat losses within distribution, increasing the share of renewable and waste heat sources within production and following advancements of integrating energy storage units and smart operating solutions. Many EU Member States are planning certain activities in the DH sector following the National Energy and Climate Plans until 2030, while more attention is paid to those countries where DH serves a high share of citizens such as the Baltic

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States. Therefore, high attention is paid to the development of advanced national planning tools and methodologies for comprehensive evaluation of possible development scenarios (Volkova et al., 2020; Zajac et al., 2019). The introduction of energy storage units and different smart operating solutions is going to increase the flexibility of the DH system (Lepiksaar et al., 2021), but still, the improvement of the production efficiency and reduction of environmental impact must be taken into account. Study (Zajac et al., 2020) shows the methods of numerical simulations validated by real data for the evaluation of heat pump introduction for the improvement of flue gas condenser efficiency on the biomass station also considering CO2 reduction. While DH sector development is shaped by the commitment of EU member states to reach carbon neutrality until 2050, DH stays among those technological solutions which can contribute to reaching ambitious goals (Lund et al., 2010). Existing studies undercovers perspectives of technological advancements for the transition from high-temperature DH systems towards 4th and 5th generation systems with the possibility to utilise lower temperatures thus providing proper exergetic prioritisation of the heating market and sources (Lund et al., 2021). Existing building stock is not yet ready to fully utilize 4th generation DH supply temperatures, and transition phase will take certain time overcoming barriers to improvement of the thermal properties of the building envelope (Attia et al., 2022; Lund et al., 2021). But during the transition phase existing natural gas boilers still will cover peak loads or will serve as backup sources and require thorough attention to operate at the highest efficiency to eliminate excess use of the natural gas. The current paper will address real case study analysis of solutions for preheating and humidifying the combustion air to prevent excess NOx emissions and increase the efficiency for the thermal energy production with natural gas boilers.

Nitrogen oxides (NOx)

The primary hazardous elements produced by the burning of natural gas and fuel oil are nitrogen oxides (NOx), which are widely recognized as significant pollutants due to their detrimental impacts on both the environment and human health. NOx emissions contribute to issues such as photochemical smog, acid rain, and ozone depletion, and can cause respiratory problems in people (Lund et al., 2021).

During combustion, NOx formation is affected by several parameters. The most important of these are combustion temperature, nitrogen content of fuel and fuel composition (Arun et al., 2012; Dutka et al., 2016), excess air and air gradation (Bělohradský et al., 2014), combustion reaction pathways, hydrodynamics, burner design and load, as also flue gas residence time (Lukáč et al., 2020).

1NOx formation mechanisms

There are presently three recognized pathways for the production of nitrogen oxides: the fuel NOx mechanism, the thermal NOx mechanism, and the prompt NOx mechanism (Korpela et al., 2015).

The fuel NOx mechanism dominates in coal combustion, while in natural gas combustion, the thermal NOx mechanism is the major contributor (Glarborg 2018).

Nitric oxide is formed during thermal reactions that require a high level of activation energy, typically above 1800° K. These reactions can be described using the extended Zeldovich mechanism (Bashtani et al., 2018):

$$O + N_2 \rightarrow NO + N, \tag{1}$$

$$N + O_2 \rightarrow NO + O, \tag{2}$$

$$N + OH \rightarrow NO + H. \tag{3}$$

The concentration of thermal nitrogen oxides rises rapidly within the combustion zone, with peak values occurring in the region of maximum combustion temperature (Baladina et al., 2020).

In fuel-rich areas, nitrogen from the air reacts with hydrocarbon radicals such as C, CH, and CN2 (generated during fuel decomposition), resulting in the production of nitrogen-containing particles like NH, HCN, and CN. These particles undergo oxidation, leading to the formation of prompt NOx (Bashtani et al., 2018). This process occurs at temperatures ranging from 927 to 1327 °C, where thermal nitrogen oxide formation does not occur.

The graphical representation of the relationship between combustion temperature and NOx formation is illustrated in Fig. 1.

While the correlation between fuel, prompt NOx, and temperature tends to be linear, thermal NOx production does not follow this trend and increases disproportionately as combustion temperature rises. (Batrakov 2015).

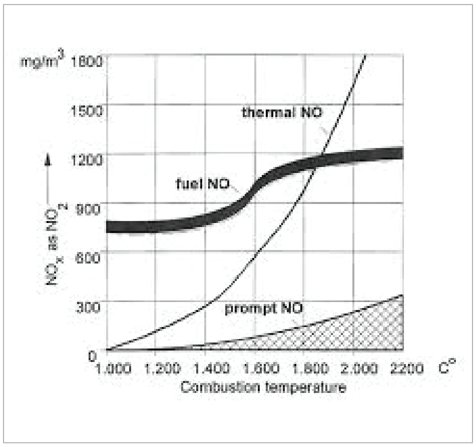


Fig. 1

The correlation between combustion temperature and the formation of NOx (TFTEI 2018)

Reducing NOx and increasing boiler efficiency

Energy resources are gradually becoming scarce and expensive (Silvy 2019), so the topic of improving boiler efficiency is becoming more and more relevant. Along with an increase in boiler efficiency, fuel consumption is reduced and therefore emissions are reduced (Si et al., 2021).

The main reason for the decrease in boiler efficiency is the heat losses with flue gases. The usual way to recover flue gas heat is to heat the return water or combustion air using an economizer. An economizer can increase boiler efficiency by 16 % and thus reduce natural gas fuel consumption by 10,6 % (Terhan et al., 2016).

But the heat recovery efficiency is limited by the flue gas dew point. To increase the flue gas dew point humidification the combustion air is used. Higher combustion air humidity corresponds to higher boiler efficiency at the same combustion air temperature (Men et al., 2019; Wei et al., 2019). In recent years, the need for more stringent environmental protection measures has grown, underscoring the importance of combating toxic emissions into the atmosphere (Zajac et al., 2020).

Both primary and secondary methods are used to reduce NOx emissions in the flue gas. Currently, selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) are the most widely used methods with high NOx reduction efficiencies (Baleta et al., 2016; Bartłomiej 2020). Popular primary methods are three-stage combustion, flue gas recirculation and OFA (over-fire air) and a combination of these methods (Bartłomiej 2020; Lukáč et al., 2020).

Air staging using overfire air (OFA) is a common practice in a pulverized coal combustion for reduction of NOx emission without deteriorating the combustion efficiency. In opposed wall-firing boilers, a simple single-level arrangement of OFA nozzles aligned with swirl burners is typically employed (Woosuk et al., 2023).

Also, humidification of the combustion air is used to reduce the combustion temperature, thus reducing the amount of NOx in the flue gases. There is a positive relationship between reducing NOx concentration and increasing combustion air humidity (Chao et al., 2017; Wei et al., 2019).

Therefore, humidification of the combustion air can both reduce the NOx emissions as well, as increase the efficiency of the boiler. On this principle is based proposed flue gas heat recovery system, which comprises a condensing heat exchanger and an enthalpy wheel.

Experimental Methodology

Description of the analyzing object

As the object of research is boiler house in Riga, which is equipped with two hot-water boilers.

Each boiler has a capacity of 9 MW and uses natural gas as the primary fuel source, with diesel as a backup fuel. Additionally, each boiler is equipped with a system for preheating and humidifying the combustion air. It is Danish technology system, called "Optinox" (Fig. 2).

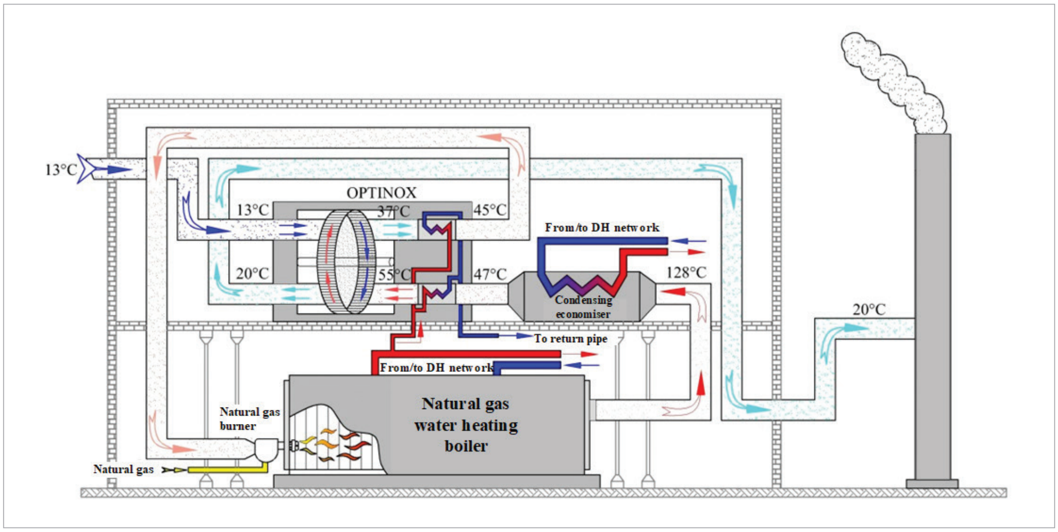


Fig. 2
Flue gas and combustion air circulation scheme in "Optinox" system

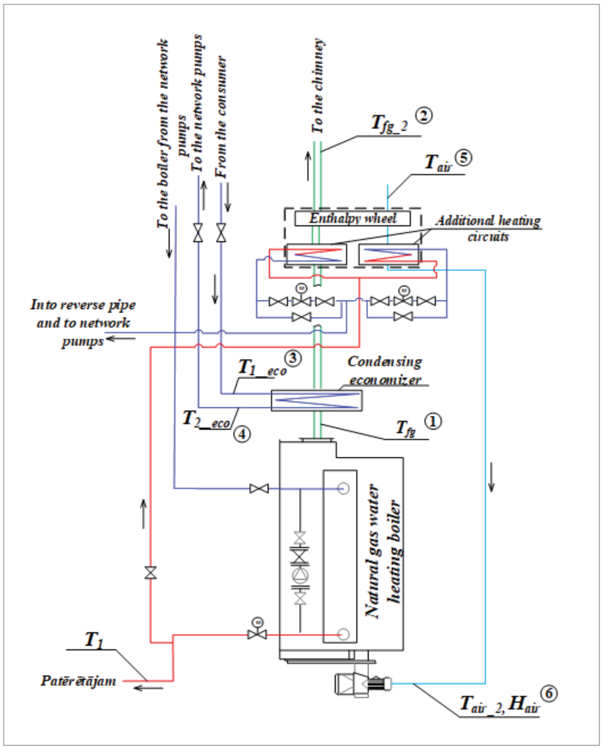


Fig. 3
Optinox system scheme

System working principle

The OPTINOX system is based on the principle that heat and moisture from the exhaust gases are transferred to the incoming air, thus heating and humidifying the combustion air and reducing the heat of the flue gases and the latent heat of the water vapor. So, there is a complete recovery between the flue gases and the combustion air.

Fig. 3 shows how does the system looks like. The combustion air humidification and preheating system includes a condensing economizer and an enthalpy wheel.

The flue gas temperature after the boiler T_{fg} is on average equal to 130 °C and after Optinox system flue gas temperature $T_{fg\ 2}$ it decreases to 25 °C on average. When the flue gases pass through the condensing economizer, they heat the return water from the consumer T_{eco} by an average of 3 °C. After economizer, reverse water goes to the network pumps and further to the boiler.

The flue gases after the condensing economizer pass through the additional heating circuit and through the enthalpy wheel. The enthalpy wheel during condensation removes heat and moisture from the flue gases, and then heat and moisture absorbed by the combustion air.

The combustion air parameters before the boiler are on average equal to: temperature $T_{air\ 2}$ = 45 °C and humidity H_{air} = 40 %.

Before Optinox system was installed, flue gases were circulating only through the condensing economizer and final flue gas temperature was not lower than 50-60°C.

Methods

Hourly average data was utilized to evaluate the efficiency of the hot water boiler both before and after the installation of the Optinox system. In December 2015, January 2016 - before Optinox was installed, December 2019 and January 2020 - after installation. For the analysis, were taken the winter months, when the boiler house operates with an increased heat load.

There is no data about economizer capacity before the Optinox installation, therefore, for comparison, only the gross boiler efficiency is calculated without taking into account the economizer.

Boiler efficiency

The efficiency coefficient of a hot-water boiler is determined by dividing the useful heat, which is used to produce steam or hot water, by the available heat of the heating boiler. The boiler's efficiency (n, %) can be calculated using either the forward balance equation (4) or the reverse balance equation (5)

$$\eta = \frac{Q}{Q_C} \cdot 100, \quad (4)$$

$$\eta = 100 - (q_2 + q_2 + q_4 + q_5 + q_6). \quad (5)$$

In equation (4), Q [kJ/kg] represents the quantity of useful heat utilized, while Qc [kJ/kg] denotes the available heat.

Available heat depends on the composition of natural gas and within the framework of this study is equal to 38021 kJ/m^3.

In equation (5), the efficiency of the boiler is directly influenced by the heat losses, namely q2 due to flue gas, q3 due to chemical underburning, q4 due to mechanical underburning, q5 from external cooling, and q6 related to the physical heat of the ash.

To calculate the boiler efficiency taking into account the economizer, the energy produced by the economizer Qeco must be added to equation (4). The final formula (6), taking into account the conversion of units of measurement and fuel consumption (natural gas), looks like this:

$$\eta_{b+eco} = \frac{(Q+Q_{eco}) \cdot 10^3}{Q_C \cdot V_g} \cdot 100. \quad (6)$$

In equation (6):

Q [MW] - the quantity of useful heat utilized; Qc [MW] – the available heat, Qeco [MW] – the heat from economizer, Vg [m^3/s] – natural gas consumption.

Flue gas analysis measurement

To evaluate the amount of NOx emissions in the flue gas, five series of flue gas analysis measurements were performed at different outdoor air temperatures (Table 1).

Measurements were performed with a flue gas analyzer Testo 350. The analysis point is located in the flue gas pipe directly after the boiler (Fig. 4). The duration of a series of measurements is 25-40 minutes. Data reading interval is 30 sec. O2 [±0,8%], CO [ppm], NOx [ppm], CO [mg/m^3], NOx [mg/m^3] and flue gas temperature [±1 °C] are measured with Testo 350. Theoretically, all these parameters are interconnected.

Table 1

Measurements under different outdoor temperature conditions

Nr.	Date	Outdoor air temperature, °C	Combustion air temperature, °C
1.	07.01.2021	-0,5	42,2
2.	15.01.2021	-10,5	51,9
3.	29.01.2021	-1,0	52,0
4.	26.02.2021	+5,0	47,9
5.	16.04.2021	+13,0	49,7

Fig. 4

The point of taking measurements.

Analisys methode

To compare the boiler efficiency before and after the installation of the Optinox system, an average value is taken for each power. Maximum and minimum efficiency values were also found for the analysis To determine this values build in function of MS Exel was used.

The analysis of the simplified data was performed by regression analysis. The main task of regression analysis is to find the relationship between independent x and dependent y values. Regression analysis was performed in MS Excel. The correlation coefficient r shows two or more variable relationships. If the coefficient approaches 1, then it is assumed that as one increases, the other also increases, but when approaching -1, then as one increases, the other decreases. If r = 0 or close to it, then there is no relation.

WaterSteamPro software was used to obtain and analyze measurement results. The software processes data in Excel, and the efficiency is calculated using the reverse balance equation (5).

For the analysis, the heat losses due mechanical underburning q4 and the heat loss with ash q6 are equal to zero. All the necessary data for the WaterStamPro program are taken from the average values of the flue gas analysis measurement and from the technical data system.

As one total heat meter is installed in the boiler house, only the total heat load of the boiler house is known, but not each boiler separately. With the help of this software, it is possible to calculate the capacity and efficiency of each boiler (with and without economizer) separately, when one of the boilers or both together are working.

Results and Discussion

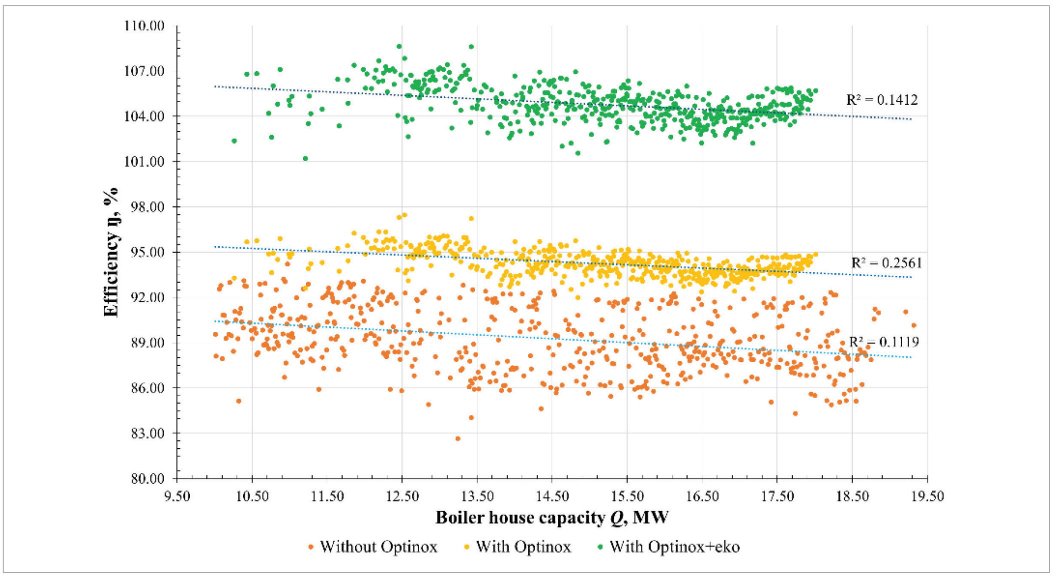
System efficiency analysis

To analyze the efficiency, the data on the overall operation of the two boilers were compared before and after the installation of the Optinox system (Fig. 5).

Fig. 5 shows the efficiency values before and after the Optinox system installation and with the Optinox system, taking into account the power of the economizer (using equation (6)). Before the

Fig. 5

Boiler efficiency before and after Optinox installation



installation of the Optinox system, the efficiency values are quite chaotic relative to the regression curve. This can be explained by the fact that before the installation of Optinox, the dew point of the flue gas was 55 °C, but after the installation, the amount of water vapor in the flue gas increased, which raised the dew point to 60 °C. This is due to humidification of the combustion air.

Thus, the outdoor air temperature and the return water temperature of the network had less effect on the efficiency, in general, the boiler house with the Optinox system operates more stable, than without it. The maximum efficiency factor n_k [%] before installing the Optinox system is 94,22 %.

When the boiler house works with the Optinox system, the efficiency values are more evenly distributed according to the regression curve. This means that Optinox systems equalize the operation of the boiler house, as well as increase efficiency by an average of 5,24 % and a maximum increase of 13,19 %.

Taking into account the capacity of the economizer, the efficiency increased on average by 15,74 % and the largest efficiency increase is 24,57 %. The maximum efficiency with the Optinox system with the economizer is equal to 108,64 %.

The physics laws do not allow to achieve real efficiency higher than 100%. However, in practice historically assessment of the efficiency of the boilers were performed using lower calorific value of the fuel. While fuel combustion technologies were not advanced enough, there was no any conflict. Nowadays, when boilers are equipped with condensing economizers, it is possible to recover heat used for the evaporation of the initial moisture in the fuel. Such situation can lead for the efficiencies higher than 100%. Obviously in terms of the laws of physics, usage of the higher calorific value is the only correct way for the assessment of the efficiency. However, from the representative point of view use of the lower calorific value gives proper values for comparison with other boilers, where producers use the same method. For this paper it was essential to show that centralised energy production is more effective, than individual and local heat production even using the latest advancements.

Heat recovery

With the enthalpy wheel of the Optinox system, the combustion air of the boiler was heated and the heat from the flue gases was removed by the economizer for return water, thus increasing the efficiency of the boiler. The flue gas temperature decrease before and after Optinox system is shown in Fig. 6.

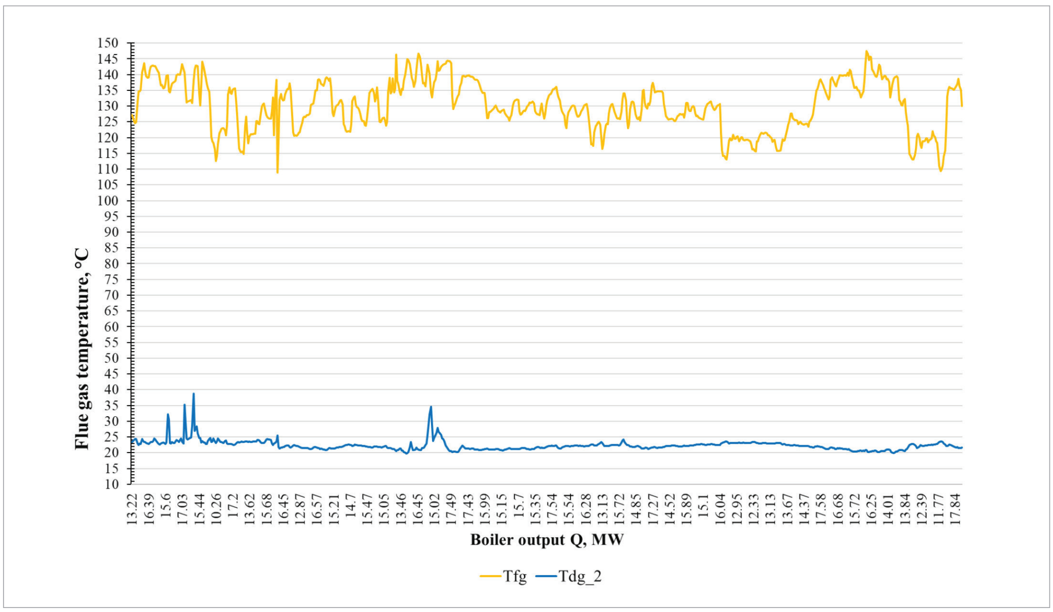


Fig. 6

Flue gas temperature before and after Optinox system

Fig. 6 shows, that the flue gas temperature after the boiler T_{fg} [°C] varies in the range from 109 °C to 147 °C at different boiler loads. As the boiler house capacity Q [MW] increases, the flue gas temperature after the boiler T_{fg} [°C] increases and the correlation coefficient is equal to 0,77.

After the Optinox system, the flue gas temperature T_{fg_2} drops to an average to 22 °C, so the Optinox system on average reduces the flue gas temperature by 108 °C.

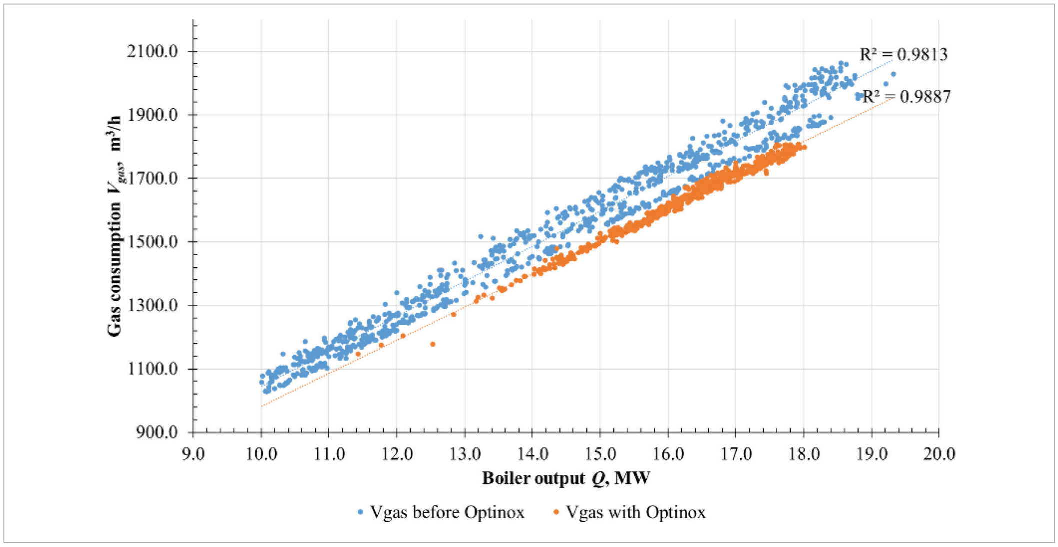
Fuel consumption

After installation of the Optinox system, the gas consumption V_{gas} [m^3/h] decreases.

Fig. 7 shows a strong linear relationship between boiler capacity Q [MW] and gas consumption V_{gas}, [m^3/h] with regression coefficients R^2 = 0,98 and 0,99. With the Optinox system, gas consumption is reduced by an average of 99,22 m^3/h or 6,11 %. The maximum gas consumption reduction was 165,68 m^3/h or 11,65 %. Gas consumption per year on average decreased by 504 832 m^3.

Fig. 7

Naturas gas consumption with and without (before installation) Optinox system



Economic calculation

To install the Optinox equipment was invested 727 500,00 €. As gas consumption decreased by 99,22 m^3/h after the installation of Optinox, the cost of gas decreased on average by 20,84 €/h (the price of gas per 1 m3 costs 0,21 €). The boiler house operates for 5 088 hours (boiler house doesn't work in summer). So, the average annual saving is 106 033,90 €/year. The repayment period is 7 years.

Analysis of flue gas measurements

Five series of flue gas analysis measurements were performed at different operating parameters. Table 2 summarizes the average values of the measurement parameters over the entire measurement period.

Table 2

Measurement results

Nr.	Date	Outdoor air temperature, °C	Wheel speed, %	Boiler output, MW	Efficiency, η_{eco}, %	NOx, mg/m^3	CO mg/m^3
1.	07.01.2021	-0,5	10	8,18	104,43	64,6	0,0
2.	15.01.2021	-10,5	8	6,25	103,06	51,6	71,5
3.	29.01.2021	-1,0	27	7,53	108,34	40,1	0,0
4.	26.02.2021	+5,0	30	6,73	107,78	84,2	0,8
5.	16.04.2021	+13,0	34	6,03	109,12	70,1	15,0

Humidity of the combustion air

The main task of the Optinox system is not only to increase the boiler efficiency, but also to reduce the emissions of nitrogen oxides. This function is performed by the wheel of the Optinox system, which humidifies the combustion air, thereby reducing the amount of NOx. The humidity of the combustion air H_{air} after the Optinox system is on average from 40 to 47 %.

During the last measurements (16.04.21) the wheel of the Optinox system was switched off and Fig. 8 shows the decrease in humidity of the combustion air.

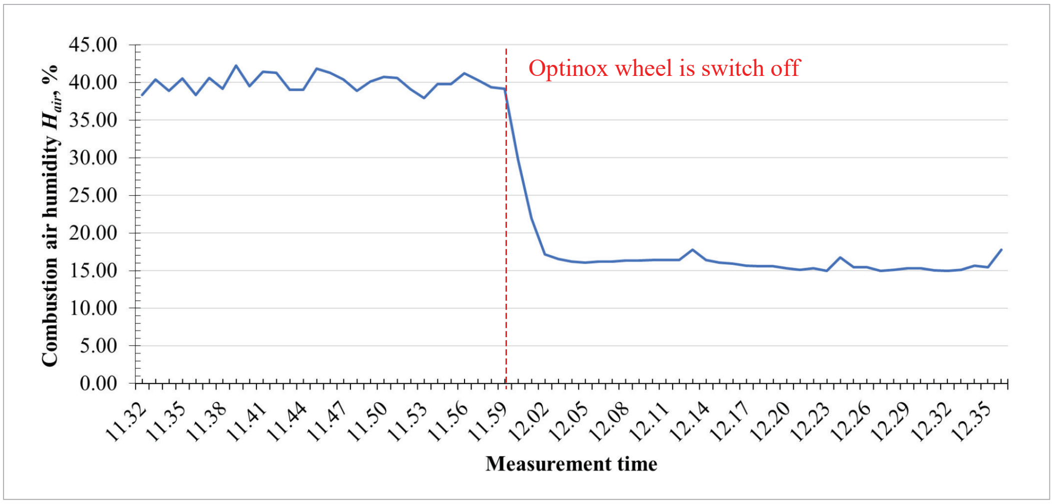


Fig. 8

Reduction of combustion air humidity after switching off Optinox wheel

The humidity of the combustion air H_m [%] decreased 2,6 times. As a result, the amount of NOx in the flue gas increased 1,7 times or by 44 %.

The amount of nitrogen oxides, oxygen and carbon dioxides in flue gases

Fig. 9 shows a correlation between the amount of oxygen and the amount of nitrogen oxides in the flue gas. After switching off the Optinox wheel, the amount of oxygen in the flue gas increases, as does the amount of nitrogen oxides. The correlation coefficient is equal to 0,95, which characterizes a strong positive correlation. At the same time combustion air humidity decreased, as is shown in Fig. 8.

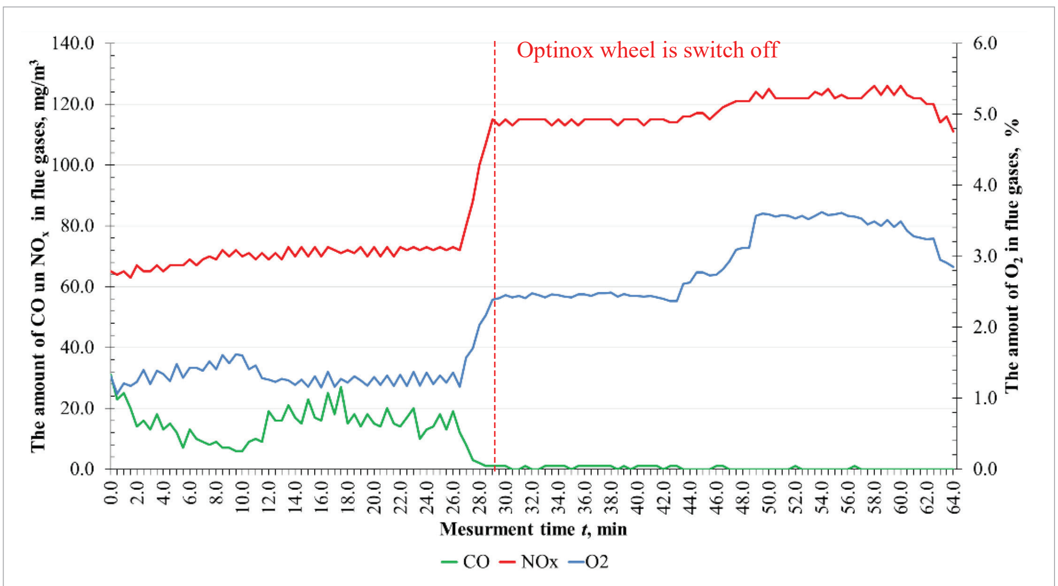


Fig. 9

The amount of CO, O2 and NOx in the flue gases before and after switching off Optinox wheel

As well **Fig. 9** shows the presence of CO before the Optinox wheel is turned off, which means incomplete combustion. This can be explained by the fact that only one boiler is running during the measurement, but the combustion air supply is installed for two boilers. There is a definite correlation between CO and NOx, so as the amount of nitric oxide increases, the amount of carbon monoxide decreases and vice versa. The correlation coefficient is -0,89.

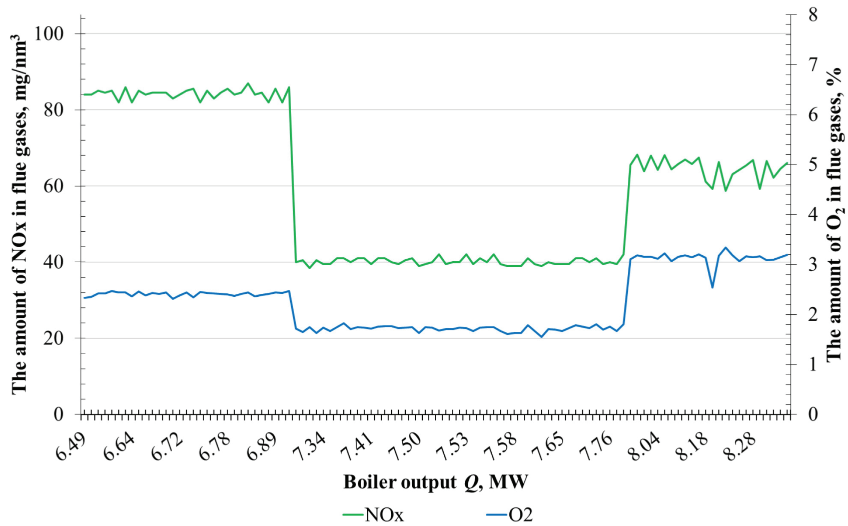
Fig. 10 shows the same relationship between NOx and O_2 as **Fig. 9.**

Fig. 10 shows that the amount of NOx in the flue gas (green line) varies depending on the amount of air (blue line) at different boiler loads.

According to the measurement data, the Optinox system reduces NOx emissions to an average of 60 mg/m^3.

Fig. 10

Dependence of NOx on the amount of air in the flue gas



Boiler efficiency

Using the reverse balance formula and flue gas analysis measurement data to determine the efficiency, the efficiency without the economizer is: 96,62 % with the Optinox system and (2) 94,62 % after switching off the Optinox system.

With economizer: and Optinox – 109,12 % and without Optinox – 104,9 %. The reduction after disconnecting the Optinox wheel is 4,22 %.

Reduction of boiler efficiency with economizer η_{b+eco} is due to reduction of combustion air humidity.

If we assume that the economizer does not work after switching off the Optinox system, then according to the received data, the Optinox system increases the boiler efficiency by 14,50 %.

Heat loses

The heat losses with flue gases according to the measurement data are summarized in **Table 3.**

According to the measurement data, the average value of the heat loss coefficient is equal to 4,43 %. If we compare the measurements made at the same load, but at different air temperatures, it can be seen that at a lower temperature, the losses were higher. After switching off the wheel of the Optinox system, the heat loses with flue gases q_2 increased by 1,98 %.

The increase in heat loss with flue gases was caused by an increase in the amount of oxygen in the flue gases (**Figure 9**). The excess air coefficient α increased by 0,12 after switching off the Optinox wheel.

Table 3
Measurement results

Date of measurement	07.01. 2021.	15.01. 2021.	29.01. 2021	26.02. 2021	16.04. 2021	16.04. 2021*
Heat loses with flue gases q2, %	5,85	5,76	3,31	3,15	3,19	5,17
Outdoor air temperature, °C	-0,5	- 10,5	- 1,0	+5,0	+13,0	+13,0
Boiler output Q, MW	8,2	6,3	7,5	6,7	6,0	6,0

* - after switching off the Optinox wheel

The analyzed Optinox system improves the boiler efficiency η_b due to the heating of the combustion air by an enthalpy wheel. The total efficiency of the boiler η_{b+eco} is increased due to the economizer and humidified combustion air (increases the recovery capacity).

The Optinox system also reduces NOx emissions in the flue gas due to the increase in humidity in the combustion air.

Conclusions

- As the object of research is hot-water boiler with capacity of 9 MW. Primary fuel sourse is natural gas and backup fuel is diesel. Boiler is equipped with a system for preheating and humidifying the combustion air. Measurements were taken at different boiler outputs from 6 MW to 8 MW.
- Humidification of the combustion air has a positive effect on the efficiency of heat recovery. As a result, the dew point temperature of the flue gases rises (from 55 °C to 60 °C), and more heat can be recovered.
- The combustion air heating and humidification system leveled the boiler room operation and maximally increased the efficiency up to 109 %. The maximum efficiency factor before installing the Optinox system is 94,22 %.
- Without an economizer, the system increases efficiency by an average of 5,24 % and the maximum increase is 13,19 %. Taking into account the capacity of the economizer, the efficiency increased on average by 15,74 % and the highest efficiency increase is 24,57 %. According to the measurement data, the combustion air preheating and humidification system increases the boiler efficiency by 14,50 % when the boiler capacity is equal to 6 MW.
- After switching off the enthalpy wheel, while boiler output was 6 MW, the humidity of the combustion air decreased 2,6 times and the amount of NOx in the flue gas increased 1,7 times. The combustion air preheating and humidification system reduces the NOx content in the flue gases to 60 mg/m^3 on average. Overall, the system has a nitrogen reduction capacity of 70 %.
- There is a positive relationship between the amount of oxygen and the amount of nitrogen oxides in the flue gas. The correlation coefficient is equal to 0,95. And there is a negative correlation, with a factor of - 0,8, between nitrous oxide and carbon monoxide in the flue gases.

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References

Arun, S., Raghuram, R., Sreenivasan, R., Vasudevan, R. , (2012), Effect of hydrogen addition in the co-flow of a methane diffusion flame in reducing nitric oxide emissions. Int. J. Hydrogen Energy 37. https://doi.org/10.1016/j.ijhydene.2012.10.016

Attia, S., Kurnitski, J., Kosiński, P., Borodiņecs, A., Deme Belafi, Z., István, K., . . . Laurent, O. (2022). Overview and future challenges of nearly zero-energy building (nZEB) design in eastern europe. Energy and Buildings, 267 . https://doi.org/10.1016/j.enbuild.2022.112165

Balandina, O., Puring, M., Vatuzov, D., Filatova, E. (2020), A study of the effect of air temperature on the possibility and rate of formation of nitrogen oxides in boiler flue gases. IOP Conf. Ser. Mater. Sci. Eng. 1. 2. https://doi.org/10.1088/1757-899X/791/1/012005

Baleta, J., Mikulčić, H., Vujanović, M., Petranović, Z., & Duić, N. (2016), Numerical simulation of urea based selective non-catalytic reduction deNOx process for industrial applications. Energy Conversion and Management, pp. 59-69. https://doi.org/10.1016/j.enconman.2016.01.062

Bartłomiej, H. (2020), Numerical Research of the Modification of the Combustion System in the OP 650 Boiler. Energies.

Bashtani, J., Sadegh, S., Bahrabadi-Jovein, I. (2018), Control of nitrogen oxide formation in power generation using modified reaction kinetics and mixing. Energy 15, pp. 567-581. https://doi.org/10.1016/j.energy.2017.12.143

Batrakov, P. (2015), The nitrogen oxide formation studying at natural gas combustion in non-circular profile furnaces of fire tube-boilers. Procedia Engineering vol. 7, pp. 144-150. https://doi.org/10.1016/j.proeng.2016.07.646

Bělohradský, P., Skryja, P., Hudák, I. (2014), Experimental study on the influence of oxygen content in the combustion air on the combustion characteristics. Energy 75, pp 116-126. https://doi.org/10.1016/j.energy.2014.04.026

Bogatova, T., Osipov, P. (2018), Общая энергетика: развитие топочных технологий 2. часть. Moskow.

Chao, L., Ke, L., Yongzhen, W., Zhitong, M., & Yulie, G. (2017), The effect analysis of thermal efficiency and optimal design for boiler system. Energy Procedia , pp. 3045-3050. https://doi.org/10.1016/j.egypro.2017.03.629

Dutka, M., Ditaranto, M., Løvås, T. (2016), NOx emissions and turbulent flow field in a partially premixed bluff body burner with CH4 and H2 fuels. Int. J. Hydrogen Energy 41. https://doi.org/10.1016/j.ijhydene.2016.05.154

Geikins, A., Borodinecs, A., & Jacnevs, V. (2022), Estimation of energy profile and possible energy savings of unclassified buildings. Buildings, 12(7). https://doi.org/10.3390/buildings12070974

Glarborg, P., Miller, J.A., Ruscic, B., Klippenstein, S.J. (2018), Modeling nitrogen chemistry in combustion. Prog. Energy Combust. Sci. 67, pp. 31-68. https://doi.org/10.1016/j.pecs.2018.01.002

Korpela, T., Kumpulainen, P., Majanne, Y., Hayrinen, A. (2015), Model based NOx emission monitoring in natural gas fired hot water boilers. Elsevier vol. 6, pp. 385-390. https://doi.org/10.1016/j.ifacol.2015.12.409

Lepiksaar, K., Mašatin, V., Latõšov, E., Siirde, A., Volkova, A. (2021), Improving CHP flexibility by integrating thermal energy storage and power-to-heat technologies into the energy system. Smart Energy, https://doi.org/10.1016/j.segy.2021.100022

Lukáč, L., Rimár, M., Variny, M., Kizek, J., Lukač, P., Jablonský, G., Janošovský, J., Fedák, M. (2020), Experimental Investigation of Primary De-NOx Methods Application Effects on NOx and CO Emissions from a Small-Scale Furnace. Processes. https://doi.org/10.3390/pr8080940

Lund, H., Möller B., Mathiesen, B.V., Dyrelund, A. (2010), The role of district heating in future renewable energy systems, Energy Volume 35, Issue 3, pp. 1381-1390, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2009.11.023

Lund, H., Østergaard, P. A., Nielsen, T. B., Werner, S., Thorsen, J. E., Gudmundsson, O., Arabkhoohsar, A., Mathiesen B. V. (2021), Perspectives on fourth and fifth generation district heating, Energy, Volume 227. https://doi.org/10.1016/j.energy.2021.120520

Men, Y., Liu, X., & Zhang, T. (2019), Performance research and application of the vapor pump boiler equipped with flue gas recirculation system. Energy Conversion and Management.

Reduction of NOx emissions. TFTEI, (2018).

Shalaj, V., Mikhajlov, A., Novikova, E., Terebilov, S., Novikova, T. (2016), Gas recirculation impact on the nitrogen oxides formation in the boiler furnace. Procedia Engineering vol. 5, pp. 434-438. https://doi.org/10.1016/j.proeng.2016.07.614

Si, M., Shen, B., Adwek, G., Xiong, L., Liu, L., Yuan, P., Gao, H., Liang, C., & Guo, Q. (2021), Review on the NO removal from flue gas by oxidation methods. In Journal of Environmental Sciences Vol. 101, pp. 49-71. https://doi.org/10.1016/j.jes.2020.08.004

Silvy, D. (2019), Energy Efficiency Improvement Strategies for Boilers: A Case Study in Pharmacy Industry. E3S Web Conf..

Terhan, M., Comakli, K.. (2016), Design and economic analysis of a flue gas condenser to recover latent heat from exhaust flue gas. Appl. Therm. Eng. pp. 1007-1015. https://doi.org/10.1016/j.applthermaleng.2015.12.122

Volkova, A., Latõšov, E., Lepiksaar, K., Siirde, A. (2020), Planning of district heating regions in estonia. International Journal of Sustainable Energy Planning and Management, 27(Special Issue), 5-16. doi:10.5278/ijsepm.3490

Wei, C., Sheng, S., Baolong, W., Xianting, L., Yang, C., Wenxing, S. (2019), Experimental study on effects of supply-air humidification on energy and emission performance of domestic gas boilers. Energy Build.

Woosuk K., Hyunbin J., Jongwook L., Kyehwan J., Changkook R. (2023), Numerical investigations on overfire air design for improved boiler operation and lower NOx emission in commercial wall-firing coal power plants, Applied Thermal Engineering,Volume 219, Part B. https://doi.org/10.1016/j.applthermaleng.2022.119604

Zajac, A., Zeiza-Seleznova, A., Rusovs, D. (2020), Impact of Flue Gas Recirculation on the Efficiency of Hot-water Boilers. Construction of Unique Buildings and Structures.

Zajacs, A., Bogdanovics, R., Borodinecs, A. (2020), Analysis of low temperature lift heat pump application in a district heating system for flue gas condenser efficiency improvement. Sustainable Cities and Society, 57. https://doi.org/10.1016/j.scs.2020.102130

Zajacs, A., Borodiņecs, A. (2019), Assessment of development scenarios of district heating systems. Sustainable Cities and Society, 48, 101540. https://doi.org/10.1016/j.scs.2019.101540

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