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RESEARCH OF LINK BETWEEN NITROGEN OXIDES AND EFFICIENCY OF PELLET BOILERS

SLĀPEKĻA OKSĪDU UN ENERGOEFEKTIVITĀTES SAISTĪBAS IZPĒTE GRANULU KATLOS

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Introduction

Climate change and dependence on fossil fuels outside the EU are the main reasons to develop renewable energy resources. These questions are included in various legislation documents. One of the last is energy and climate packet for year 2020, in which a goal for Latvia is established – to increase proportion of renewable resources to 42%. At the moment one very qualitative renewable fuel is taking a special position in Latvia's economy – wood pellets. Lately multiple pellet factories have been built.

Usage of compressed biomass fuels (pellets, briquettes) allows establishing and developing fully automatic heating systems not only for commercial objects, but also for residential buildings. Pellet combustion systems are as comfortable as equal gas, liquid fuel heating systems.

More important are becoming concerns about developing qualitative and energy efficient pellet combustion processes that includes not only pellet boiler's efficiency, but also emissions of environmentally harmful gases. In this situation the most important air basin pollutant is nitrogen oxide.

The produced quantity of nitrogen oxide during combustion processes depends on concentration of nitrogen in the fuel and its formation mechanism. At the moment there is three known nitrogen formation mechanisms where fast, thermal and combustion nitrogen oxides are produced.

This article contains analysis of nitrogen oxide formation processes in pellet combustion boiler and research of its energy efficiency, from view of various pellet quality describing parameters, to set up goals for pellet boiler and pellet quality criteria in Latvia.

Defining combustion efficiency

Combustion efficiency of the boiler is defined using the guidelines of EN 303-5 standard. In the mentioned standard two methods of determining boiler efficiency are described – direct and indirect methods. In this investigation direct method is used.

Using direct method boiler efficiency is defined as the ratio of useful energy output and fuel energy input [1]:

$$\eta_K = \frac{Q}{Q_B} \tag{1}$$

where

η_K – boiler efficiency;
Q – useful energy output in the set period of time, kWh;
Q_B – fuel energy input in the set period of time, kWh.

The amount of useful heat produced by the boiler depends on the difference between input and output feed water temperature and is defined using the following formula [1]:

$$Q = w_1 \times c_{w1} \times (t_V - t_E) \tag{2}$$

where
w_1 – water flow in the boiler in the set period of time, kg;
c_{w1} – heat capacity of the water at t_E, J/(kg*K);
t_V – input water temperature, °C;
t_E – output water temperature, °C.

Defining boiler efficiency is based on net calorific value of the fuel H_U. Fuel heat input (Q_B, J) of the boiler is determined using the formula [1]:

$$Q_B = B \times H_U \tag{3}$$

where
B – boiler fuel input, kg;
H_U – net calorific value of the fuel, J/kg.

Experimental apparatus

For the experiment pellet boiler with 15 kW capacity and automatic fuel and air input system was used.
The boiler is equipped with semi-automatic operation system. It means that user has to ignite the fuel in combustion camera manually and to clean the boiler regularly. When continuous combustion is reached, the boiler operates automatically. The boiler automatically supplies pellets to the burner and turns off after reaching maximal water temperature. When the boiler stops operating, it switches off air ventilator and fuel input system. The coals in the burner are blazing and, when the temperature of water decreases, burning process is renewed. If there are no live coals in the burner, an operator has to fulfill it and to ignite the pellets. Fuel injection from pellet tank is realized using worm screw. The boiler is equipped with fuel lack warning system. The boiler is also equipped with three-way valve for regulating output water temperature. There is an independent circuit with separate circulation pump, therefore output water temperature is regulated using the valve, by mixing the water from heating loop with the water from boiler internal loop.
The scheme of the experimental system is shown on the Figure 1.

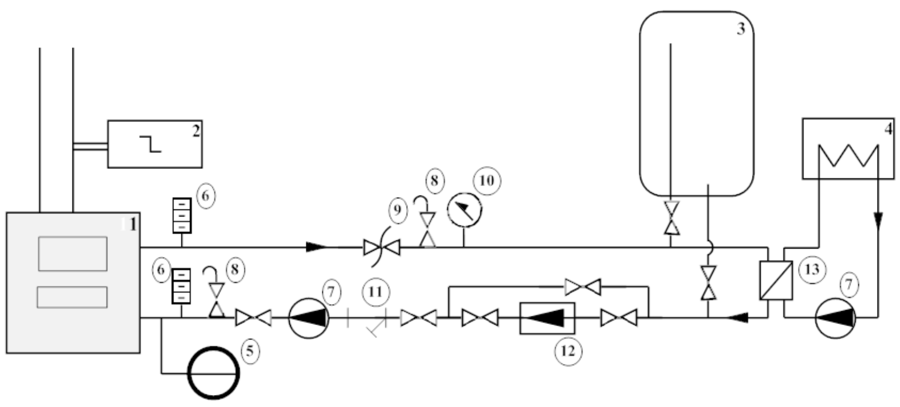

Figure 1. Scheme of boiler testing stand (1 – pellet boiler, 2 – flue gas analyzer, 3 – 360l water accumulation tank, 4 – hot water cooler, 5 – expansion vessel, 6 – temperature sensors, 7 – circulation pumps, 8 – deaerator, 9 – safety-valve, 10 – manometer, 11 - filter, 12 – electromagnetic water flow sensor, 13 – heat exchanger)

As heat load is necessary for normal operation of the boiler, hydraulic system includes cooler and heat storage tank. The cooler in point of fact is a water-air heat exchanger equipped with three ventilators to provide air flow and to cool the water. The water cooler loop is separated from boiler water loop by heat exchanger, because pressure in the cooler should not exceed 1 bar, but rated pressure of the boiler is 1 bar and this value is often exceeded.

Quality parameters of pellets

For the experiment there were five pellet samples used, which differed one from each other by humidity, ash content, mechanical durability and net calorific value. All the acquired pellet quality parameter values, which were collected during the experiments, can be seen in Table 1.

Table 1.

Pellets testing results

Pellet sample	Moisture content, w-%	Ash content, w-%	Mechanical durability, %	Fines, w-%	Net calorific value, MJ/kg
1st sample	8.5	0.39	99.14	1.23	17.01
1st sample (wet)	13.6	0.39	97.36	1.23	15.94
2nd sample	7.2	0.71	98.13	0.54	17.30
3rd sample	8.5	0.50	95.97	0.62	17.44
4th sample	9.7	1.63	97.14	0.83	16.68
5th sample	11.5	0.29	96.15	0.83	16.74

To evaluate how moisture affects pellets and boiler's operating results, the first pellet sample was stored in an open box for 8 days in a room with high humidity level. During this experiment air's relative humidity changed from 58% to 90%. Periodically pellet moisture content was determined and the results can be seen at Figure 2.

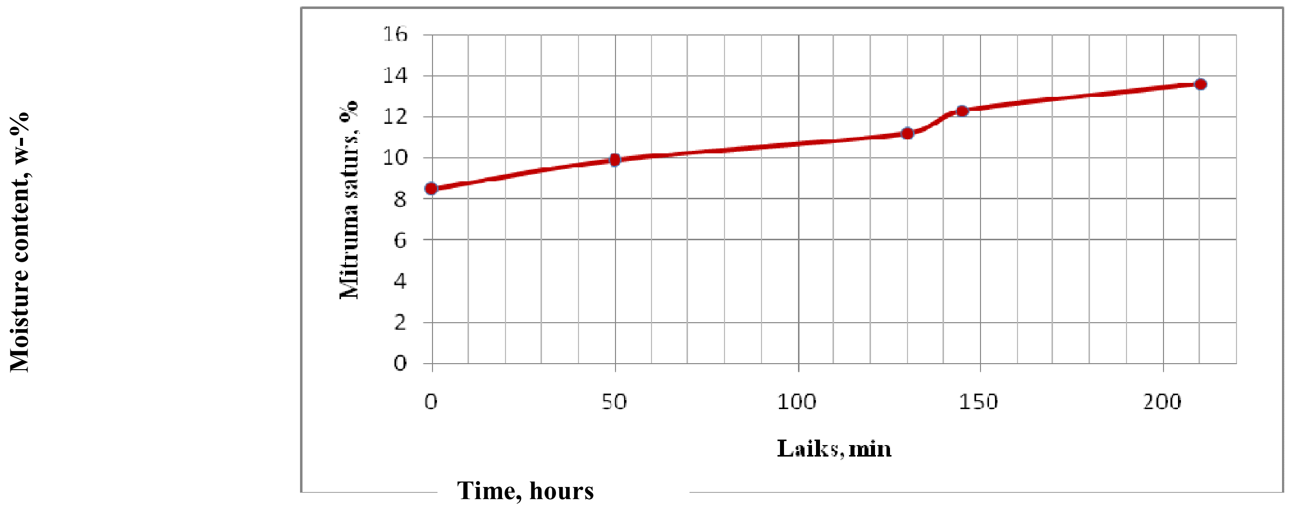

Figure 2. Moisture content changes in pellet sample

During the experiment a slight change in pellet shape and some fissures was noticed because of influence of air humidity. After this experiment pellet mechanical durability was tested. After holding the pellets for 210 hours in high air humidity room, pellet moisture content increased by 5.1 % and mechanical durability decreased by 1.78%.

Concentration of nitrogen oxides in flue gas

During the pellet combustion process, boiler's flue gas analysis was performed with automatic flu gas analyzer Testo350XL. The analyzer uses infra-red rays to determine concentrations of various flue gas components. Testo350XL is equipped with air-pump, filters and condensation device to sample collection and preparation. Integrated feeding units and data logger allows the analyzer to work without interruption for 8 hours.

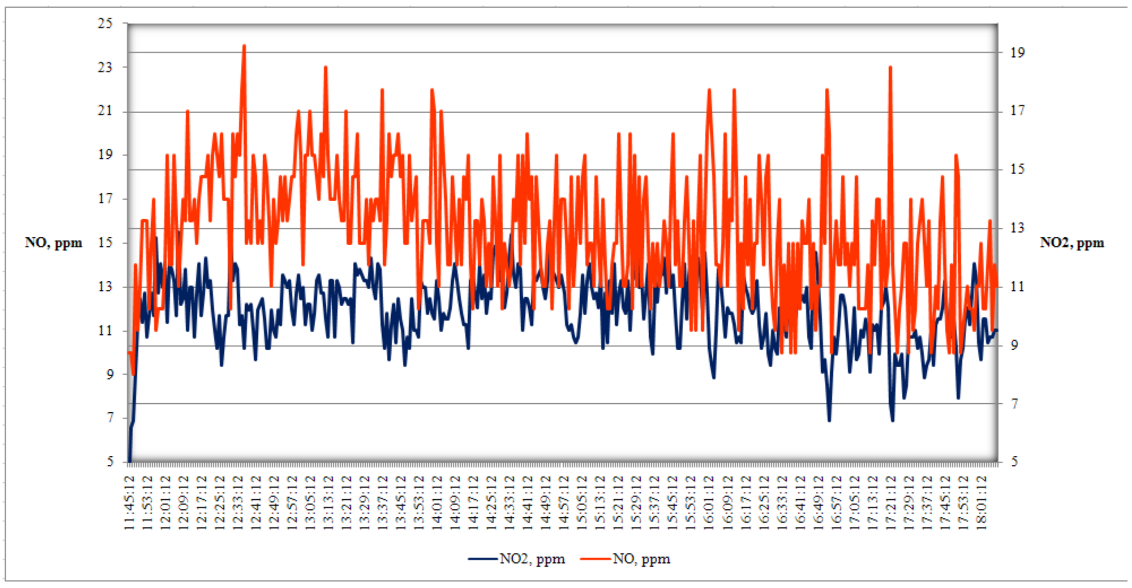

Figure 3. Parameters of 1st pellet sample burning process: NO and NO_2

For the flue gas analysis analyzer was equipped with O_2, CO, NO_2, NO, SO_2 and H_2 sensors. The sampling probe was equipped with temperature sensor to measure temperature of flue gas.

For measurements the probe was installed at the centre of flue pipe at the boiler's exit. Measurement step for data-logger was set to 1 minute, because it wasn't intended to determine flue gas parameter values at starting and turning off periods.

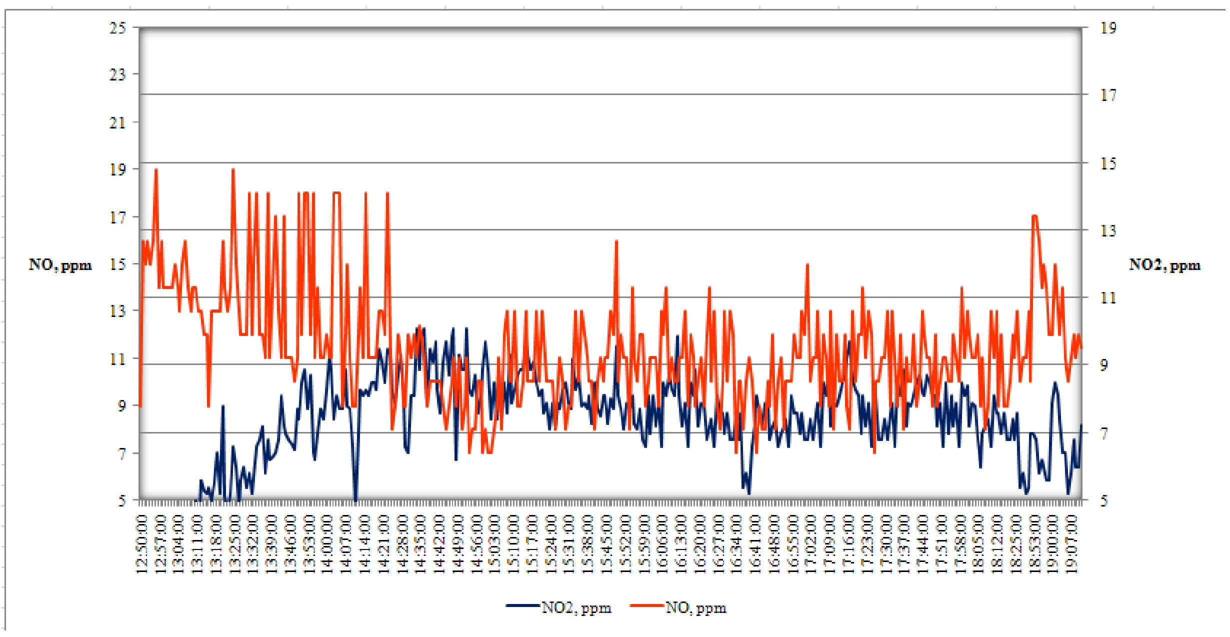

Figure 4. Parameters of 1st pellet wet sample burning process: NO and NO_2

- Acquired nitrogen oxide concentration changes for two pellet samples (first sample and humid part of first sample) during combustion can be seen at Figure 3. and Figure 4. According to acquired values, the dry sample has larger nitrogen oxide fluctuations. Especially it applies to nitrogen monoxide (NO).

- Experimental data confirms that average levels of both nitrogen oxide values are lower for humid pellets. Nitrogen dioxide values decreases for 20% and nitrogen monoxide – for 30 %. It can be explained with a decrease of thermal nitrogen oxide in presence of OH radical in humid pellets.

Experimental results

The characteristic parameters gained in experiments that describe furnace operation and pellets parameter values were analyzed to find coherence between different parameters groups. To gain this goal were used two variable amount correlation method.
Average flue gas components concentrations and flue gas temperatures average value findings during furnace energy efficiency determination and calculated furnace energy efficiency values are in Table 2. Further results are analyzed for NO_x, CO, CO_2 concentrations. There are not included SO_2, O_2 and H_2 concentrations. Total amount of nitrogen oxides was calculated as sum between NO and NO_2.

Table 2.

Boiler testing results

Pellet sample	Average concentrations of flue gas components			Flue gas average temperature, °C	Boiler efficiency
	NO_x, ppm	CO, ppm	CO_2, %		
1st sample	25.71	263	4.31	113	0.74
1st sample (wet)	18.73	359	4.63	106	0.70
2nd sample	31.52	199	4.57	117	0.78
3rd sample	33.89	182	4.71	117	0.72
4th sample	34.61	201	4.05	112	0.69
5th sample	---	---	---	---	0.73

Overall the influence of five pellet samples to boiler's operation efficiency, average flue gas temperature and average concentration levels of NO_x, CO and CO_2 were tested. Simple correlation method was used. That is why there are 25 correlations checking between each pellet parameter and boiler's parameter. In this article there are graphics describing the correlation between moisture content in pellets and boiler's operation parameters.
After analysis of measurement data a conclusion arises that average level of nitrogen oxide concentration depends on pellet's moisture content (Figure 5). In this case it can be seen that, moisture content in pellets just partly influences nitrogen oxide concentration in flue gas. Theoretically the largest amount of NO_x is being produced at high temperatures, but increasing the moisture content in pellets, combustion temperature decreases.

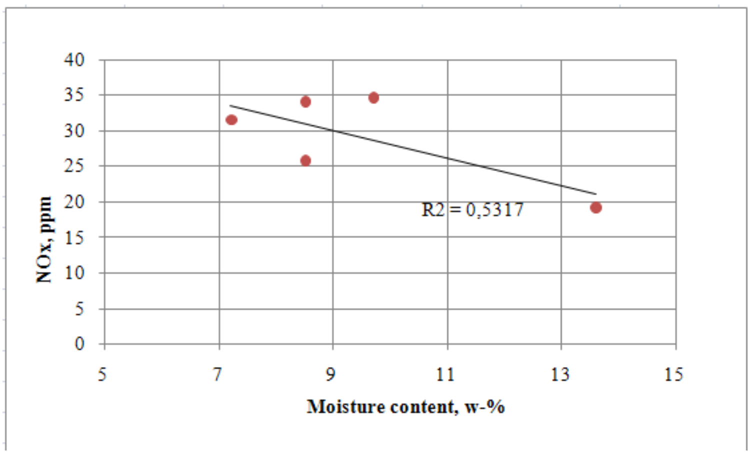

Figure 5. Correlation between moisture content and average NO_x concentration

From other hand, it is necessary to research humid pellet influence to boiler's efficiency. Influence of moisture content in pellets to the boiler's performance can be seen at Figure 6. In the graph it can be seen that correlation exists between moisture content and boiler's efficiency, but the coefficient of correlation R^2 doesn't have high value.

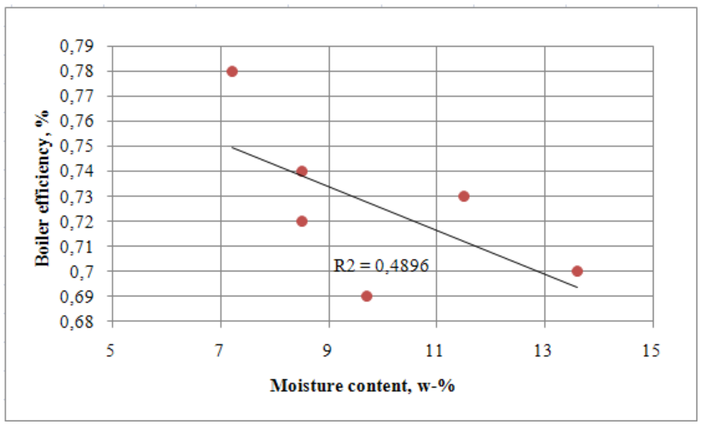

Figure 6. Correlation between moisture content and boiler efficiency

Because boiler's energy efficiency is a complex value, which depends on various parameters, to improve the correlation, it is necessary to increase amount of input data. It can be achieved using more than five pellet samples for the experiments and detailed research of current samples.

Boiler's efficiency expressed with multi-parameter correlation function.

During the research a statistic analysis between pellet parameters and boiler's efficiency was performed. Analysis was achieved using statistical function LINEST, which expresses influence of many independent parameters to one specific parameter with help of regression line.
As a specific parameter boiler's efficiency was taken and as other parameters moisture content, ash content, amount of fines and net calorific value was chosen.
Gained equation (4) describes influence to boiler's efficiency of pellet moisture content, ash content, amount of fines and net calorific value. For calculated regression line, the R^2 coefficient is equal to 0,857, which indicates strong correlation between all 4 parameters and boiler's performance.

$$y = -0.0271 \times x_1 - 0.0579 \times x_2 - 0.0678 \times x_3 - 0.1 \times x_4 + 2.787 \qquad (4)$$

where
y – boiler's efficiency;
x_1 – moisture content in pellets, w-%;
x_2 – ash content in pellets, w-%;
x_3 – amount of fines in pellets, w-%;
x_4 – net calorific value of pellets, MJ/kg.

As LINEST function uses regression line for data analysis, highest precision of equation (4) can be achieved using values between used min and max input-data x values. Inputting pellet parameter values, which are outside mentioned limits, calculated boiler's efficiency will be forecasted.
Pellet parameters max and min values, which forms the credibility limits and random values inside and outside these limits, were used to verify the equation
At the beginning pellet mechanical durability was taken as one of the pellet parameters to influence boiler's efficiency, but further analysis showed that it destabilizes system of variables.
Enhancing LINEST function with larger amount of dependent and independent values and pellet parameters, it is possible to gain more precise equation for boiler's efficiency. Gained equation is usable only with those values, which satisfies the credibility interval, and that's why it is useful to use pellets with drastically different parameter values. With help of LINEST, knowing the pellet quality characterizing values, it is possible to calculate boiler's efficiency without actually testing it.
LINEST calculated moisture content influence on boiler's efficiency is illustrated at Figure 7.

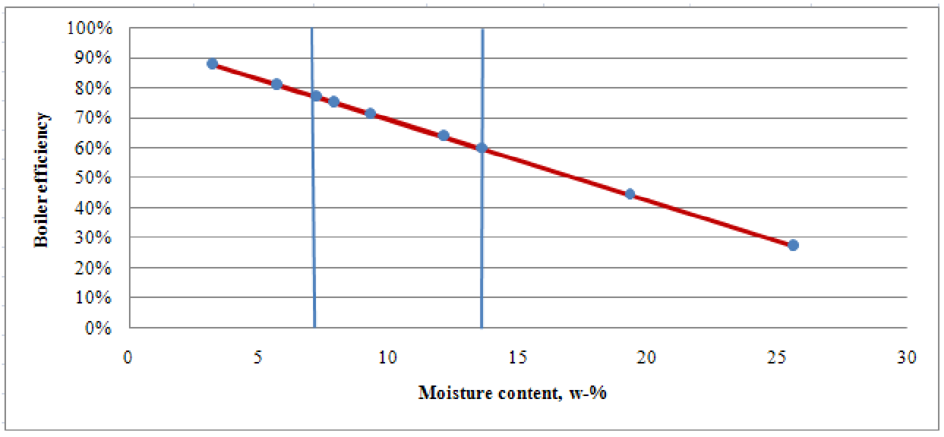

Figure 7. Calculated boiler efficiency in function of variable moisture content

Conclusions

1. The change of nitric oxides concentration in flue gases during the burning process of two pellet samples (1st sample and 1st wet sample) is shown on Figures 3. and 4. Experimental data shows that during burning of the dry sample there are greater fluctuations of nitric oxides concentration. In particular it concerns nitric monoxide (NO).
2. Experimental data confirms also that the average concentration of both nitric oxides is lower when the wet sample is burned. Nitric dioxide concentration in flue gases decreased by 20% and nitric monoxide concentration – by 30%. Average decrease of NOx concentration is ~25%. It is explainable with decreasing of thermal oxides influenced by OH radical when moisture content in pellets is greater.
3. Pellets with greater moisture content negatively influence boiler efficiency, which decreases by 4% during certain pellet sample burning process. It points to conclusion that reduction of nitric oxides by 7% is reached by decreasing boiler efficiency by 1%.

References

1. LVS EN 303 – 5 „Heating boilers - Part 5: Heating boilers for solid fuels, hand and automatically stocked, nominal heat output of up to 300 kW - Terminology, requirements, testing and marking" // European standard. – (April 1999).

Žandeckis A., Rochas C., Blumberga D., Boloņina A., Siliņš K. Slāpekļa oksīdu un energoefektivitātes saistības izpēte granulu katlos
Klimata pārmaiņu samazināšana un atjaunojamo energoresursu izmantošanas veicināšana ir svarīgi Eiropas Savienības vides politikas mērķi. Viens no atjaunojamajiem energoresursiem, kas plaši tiek izmantots nelielas jaudas siltumenerģijas avotos, ir biomasa. Attīstoties koksnes apstrādes un sadedzināšanas tehnoloģijām un paaugstinoties katlu iekārtu automatizācijas līmenim, arvien populārāks kļūst sablīvētais biomasas kurināmais – granulas un briketes.
Raksts ir veltīts eksperimentālajam pētījumam, kura mērķis bija veikt granulu katla testēšanu, ka arī noteikt eksperimentam izmantoto koksnes granulu kvalitāti raksturojošo parametru vērtības. Eksperimentu laikā iegūtie rezultāti tika analizēti ar mērķi noteikt granulu parametru ietekmi uz katla darbības rādītājiem, īpaši uz NO_x emisiju līmeņi. Datu analīzei tika izmantotas gan vienkāršas, divu manīgo korelācijas funkcijas, gan vairāku manīgo funkcija (LINEST).

Zandeckis A., Rochas C., Blumberga D., Boloņina A., Silins K. Research of link between nitrogen oxides and efficiency of pellet boilers
To reduce climate changes and to encourage usage of renewable energy resources are very important goals for EU. One of the resources, what is widely used at small power thermal energy sources, is biomass. Development of wood processing and incineration technologies and an increase of boiler's automatization level, the more popular becomes impacted biomass fuel – pellets, briquettes.
This paper is contributed to experimental research, which goal was to test pellet boiler and to determine pellet quality characterizing parameters. Results of the experiment were analyzed to determine pellet quality influence to boiler's performance, especially taking into account NO_x. Simple and two variable correlation functions and multi-parameter function (LINEST) was used for the analysis.

Жандецкий А., Роша К., Блумберга Д., Болонина А., Силиньш К. Исследование связи между уровнем выбросов NO_x и эффективностью работы гранульных котлов
Уменьшение изменений климата и использование возобновляемых энергоресурсов являются важными целями политики охраны окружающей среды в Европейском союзе. Биомасса, один из видов возобновляемых энергоресурсов, широко используется в небольших источниках тепловой энергии. С развитием технологий сжигания древесины и повышением степени автоматизации котельных установок биотопливо из прессованной древесины – гранулы и брикеты, становится все более популярным.
Статья посвящена экспериментальному исследованию, целью которого являлось тестирование гранульного котла, а также определение параметров, характеризующих качества гранул. Данные, полученные в ходе экспериментов, были проанализированы с целью определения влияния параметров гранул на показатели работы котла, особенно уровень выбросов NO_x. Для анализа зависимостей использовались как простые функции, состоящие из двух переменных, так и сложная функция, включающая несколько переменных (LINEST).