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RESEARCH OF FORMATION OF NITROGEN MONOOXIDES DURING PELLET COMBUSTION

SLĀPEKĻA MONOKSĪDU VEIDOŠANAS MEHĀNISMU IZPĒTE GRANULU DEGŠANAS PROCESĀ

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Introduction

In his study a pellet boiler with nominal heat capacity of 15 kW was tested. For experiments wood chip pellets were used, which were acquired from numberous producers. Pellet quality parameter values were determined for each sample. During each combustion test a temperature of flue gases, O_2, CO_2, CO and NO concentrations in the flue gases were determined. After each test boilers efficiency was calculated using direct method.
Overall, 11 boiler tests were done and acquired results were analyzed to determine parametrs, which infuences NO concentration in flue gases. For data processing two-parameter correlation method was used.

1. Nitrogen oxides in flue gas

NO emission formation process is divided into three main mechanisms: thermal NO, fuel NO and nitrogen monoxide generation through N_2O. Thermal NO is formed in the flame zones of high temperatures, usually above 1600 ° C, and its formation intensity depends on residence time of nitrogen in high temperature zone [1,2]. The flame temperature inside furnace does not depend only on the furnace inner construction properties but, it is also influenced by moisture content of fuels and supplied air quantity to the furnace. These two factors must be taken into account carrying out boiler-testing and adjustment.

At lower temperature zones it is possible that NO is formed from N_2O-intermediate mechanism, starting from third body recombination reaction. During biomass combustion, the nitrogen monoxide is formed in relatively large quantities through the fuel-NO formation mechanism. This is explained by the fact that biomass fuels have relatively high nitrogen content [1].

2. Methodology tests

In the initial procedure was expected to use six different pellet samples and to provide for each kind of pellet six hour boiler tests according to standard EN 303-5 methodology. Overall, 11 boiler tests were made, five with unregulated air supply system and the six tests with decreased air supply to the furnace. During the experiments the return water temperature to the boiler was kept at 50±1 ^{o}C and water flow rate in the hydraulic circuit was equal to 0.6±0.05 m^3/h.
The control system of the experimental boiler works only using an on/off principle; during the boiler operation a constant amount of fuel and oxygen is provided to the furnace, hence there is not possibility for an ordinary operator to regulate boiler capacity. In consequence of that only tests at nominal capacity have been carried out.

3. Equipment for tests

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.

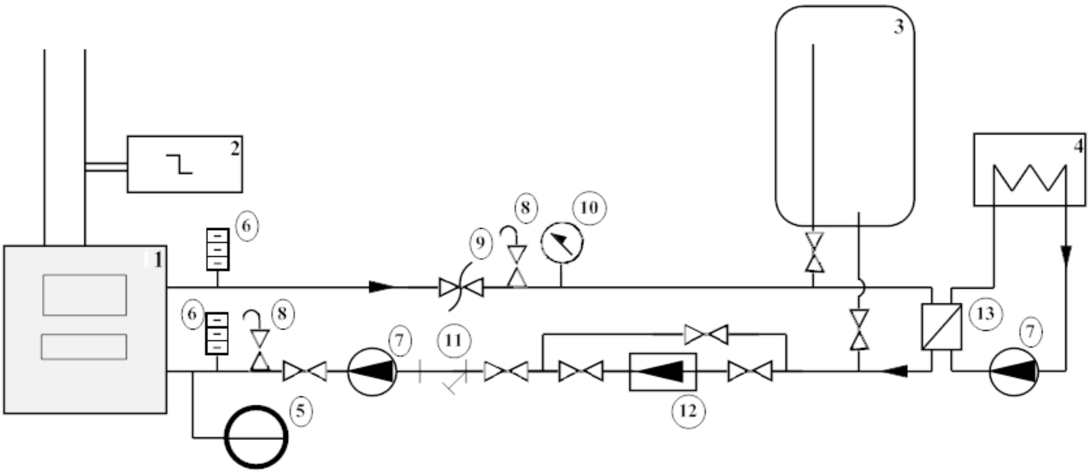

Fig.1. Scheme of boiler testing stand (1 – pellet boiler, 2 – flue gas analyzer, 3 – 360l water accumulation tank, 4 – hot water cooler, 5 – expansion vessel, 6 – temperature sensors, 7 – circulation pumps, 8 – deaerator, 9 – safety-valve, 10 – manometer, 11 - filter, 12 – electromagnetic water flow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

As heat load is necessary for normal operation of the boiler, the hydraulic system includes a heat sink and a heat storage tank. The heat sink is a water-air heat exchanger equipped with three ventilators to provide air flow and to cool the water. The heat sink loop is separated from the boiler water loop by a flat plate heat exchanger.

For flue-gas monitoring a stationary modular flue gas analyzer has been used. It consists of a continuous non-dispersive infrared absorption gas analyzer module in the $\lambda = 2.5$–8 μm wave length range for measuring carbon dioxide, carbon monoxide and nitrogen monoxide. The magneto mechanical oxygen continuous analyzer based on the paramagnetic behavior of oxygen principle was used for measurements of oxygen concentration. The analyzer set up includes flue gas pump, heated connecting line, filters, condensing and feeding unit for collection and preparation of gas samples.

For flue-gas temperature measurements five K-type thermocouples were placed inside the flue stack and draught measurements were made using pressure-vacuum sensor.

4. Pellets

Pellets samples for the experiments have been purchased from six different industrial producers and sample identified at No. 3 for a set of tests moisture content was artificially increasing. Additionally two other pellet samples were formed. Before boiler tests moisture content, ash content, net calorific value, mechanical durability and amount of fines were determined for all pellet samples according to CEN / TS standard methodology. Additionally, nitrogen content was determined for samples 1., 2. and 3.1. Pellet parameter values measured during the analysis are summarized in table 1.

Table 1.

Pellets used for boiler tests

Pellets	Moisture content, %	Ash content, %	Net calorific value, MJ/kg	Nitrogen content, %	Mechanical durability, %	Fines, %
1. sample	6.29	0.43	17.46	0.10	97.63	0.66
2. sample	6.14	0.56	17.39	0.11	97.42	0.37
3. sample	8.5	0.39	17.01	---	99.14	1.23
3.1. sample	8.75	0.39	16.95	0.09	98.42	1.23
3.2. sample	13.6	0.39	15.94	---	97.36	1.23
4. sample	7.2	0.71	17.30	---	98.13	0.54
5. sample	8.5	0.50	17.44	---	95.97	0.62
6. sample	9.7	1.63	16.68	---	97.14	0.83

Overall, 11 combustion tests were made using pellets from six different manufacturers. For pellet samples No. 1, 2 and 3.1. boiler test procedure was repeated.

5. Results of combustion tests

During boilers tests, flue gas monitoring was carried out to determine O_2, CO_2, CO and NO concentrations and temperature. Boiler efficiency was calculated using direct method after each boiler experiment. The results are summarized in table 2. In this table are reported emission concentration and flue gas temperature average values. Average concentrations of CO and NO are recalculated to 10% of oxygen concentration in flue gases.

Table 2.

Pellets used for boiler tests

Test	Pellets	O_2, %	CO_2, %	CO, ppm (at 10% O_2)	NO, ppm (at 10% O_2)	Flue gas temperature, °C	Boiler efficiency, %
1.1.	1. sample	6.13	13.91	442.7	75.77	94.7	86.4
1.2.	1. sample	6.80	13.34	409.2	75.75	92.6	86.3
2.1.	2. sample	7.04	13.74	248.0	97.02	94.6	84.7
2.2.	2. sample	7.54	12.99	205.6	96.03	96.1	83.9
3.1.	3.1. sample	11.77	8.67	539.0	67.04	85.6	84.1
3.2.	3.1. sample	10.16	10.14	262.2	67.39	84.0	84.7
3.3.	3. sample	16.93	4.31	923.5	54.57	81.7	74.1
3.4.	3.2. sample	17.42	4.63	1415.4	45.26	77.3	70.1
4.1.	4. sample	16.77	4.57	673.7	62.29	82.4	78.0
5.1	5. sample	16.34	4.71	558.2	49.07	81.7	72.2
6.1.	6. sample	17.21	4.05	753.9	45.12	79.8	68.8

The collected data from the tests were analyzed to determine supplied air quantity, flue gas temperature, moisture and nitrogen content impact on the NO concentration in the flue gases. Thermal NO oxide formation is a function of flame temperature inside the furnace and is affected by various factors. On existing installations, the temperature inside the furnace can be changed regulating supplied air quantity [3]. On the figure 2 is shown average correlation between oxygen and NO concentrations in the flue gases. It proves that an increase of supplied air quantity in the furnace results in reduction of nitrogen monoxide average concentration. Whole data set in this analysis consists of 11 boiler test results: 5 tests were conducted on unregulated air feeding and 6 tests at reduced air supply. After five experiments supplied air volume within boilers furnace was reduced to approximately half. This resulted in a reduction of NO by 35% and the boiler efficiency decreased for approximately 10%. The expected drop in boiler efficiency is related to higher flue gas heat losses. It happens because the total quantity of combustion products increases and more heat is removed from the boiler through a flue stack with them.

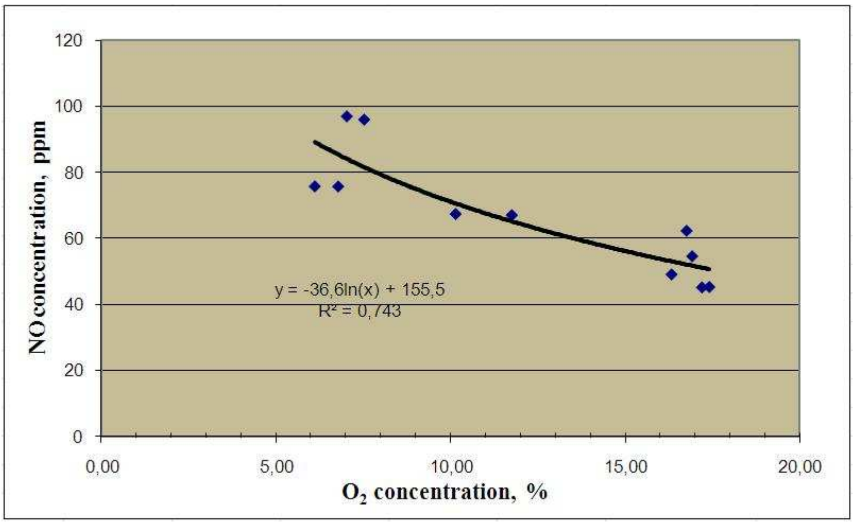

Fig. 2. Comparison of NO-concentrations recalculated at 10% of O_2

On the picture 3 there is shown a relationship between absolute nitrogen monoxide and oxygen concentrations in the flue gas during one experiment. The chart characterizes NO and O_2 concentration fluctuations in one-hour long combustion of one sample. During one boiler test volume of air supplied inside the furnace is constant, but oxygen concentration fluctuations in flue gases can be explained with changing intensity of combustion process and momentum quantity of fuel inside furnace. These two factors affect both the temperature inside the furnace and with fuel injected nitrogen amount inside furnace, which determines the intensity of the NO formation mechanism

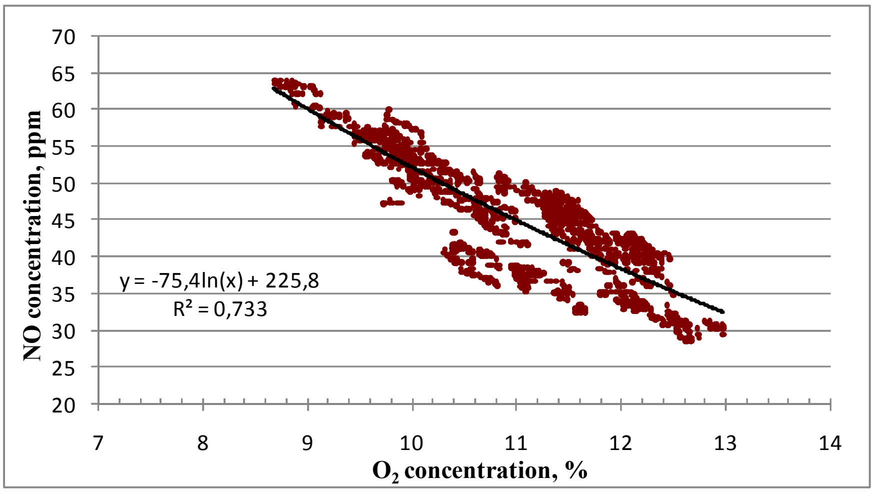

Fig.3. Correlation between O_2 and NO concentrations during one test

One of the typical nitrogen monoxide source is thermal NO formation mechanism, which depends on intensity of the flame temperature in the furnace [1,2]. The figure 4 shows the correlation between the flue gas average temperature and the average NO concentration in the flue gases. Temperature of flue gases is a direct function of the temperature inside boiler furnace, therefore when the exhaust gas temperature increases the concentration of nitrogen monoxide also increases.

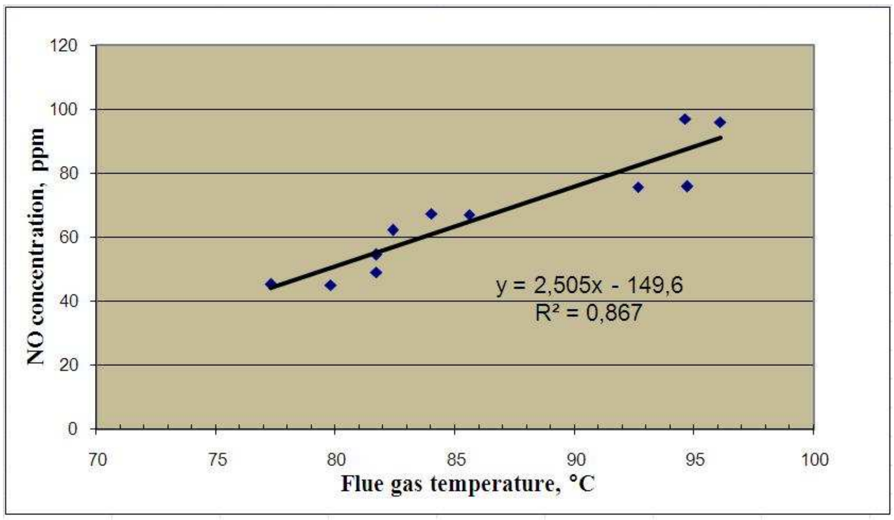

Fig. 4. Correlation between average flue gas temperature and NO concentration

During the burning process moisture of the existing fuel is evaporated and the process consumes additional thermal energy. The higher fuel moisture content the lower temperature inside the furnace chamber which results in decline of boilers efficiency. Figure 5 shows the relationship between the moisture content of pellets and the average NO concentration in flue gas.

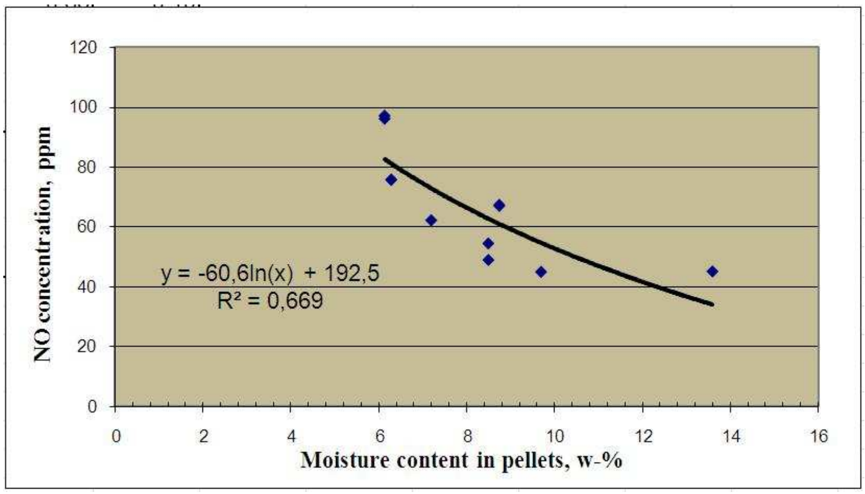

Fig. 5. Correlation between moisture content in pellets and NO concentration

During the experiments two boiler test (3.3. and 3.4.) were performed with the same pellets, but with a different moisture content. Increase of moisture content was achieved storing pellets in a place with a relative humidity of 70 - 90%. In both experiments, the air feeding system was operating at similar rate. Pellets with a moisture content of 8.5% were used for test 3.3. and pellets with a moisture content of 13.6% were used for test 3.4. The results show that the same pellet samples with an increase of moisture content from 8.5% to 13.6% resulted a decrease in average nitrogen monoxide concentration by 17% (from 54.57 ppm to 45.26 ppm at 10% O_2) and the boiler efficiency decreased by 4%.

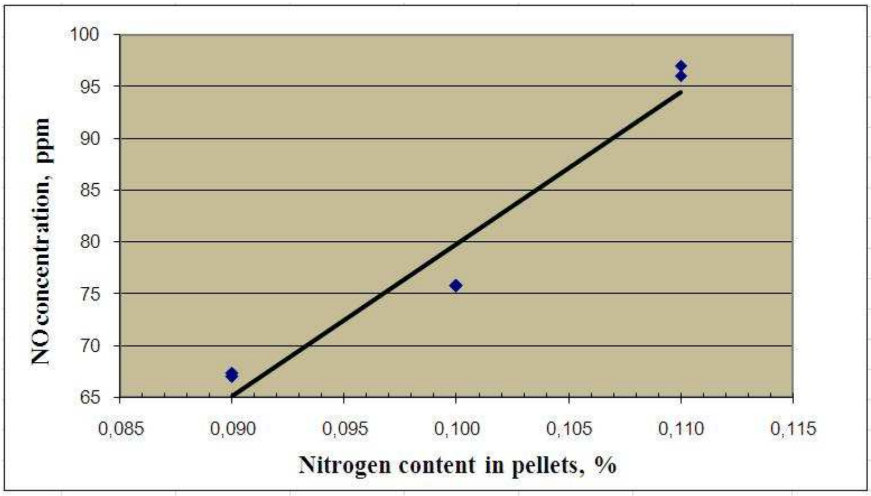

Fig. 6. Correlation between nitrogen content in pellets and NO concentration

Nitrogen content for pellet samples No. 1, 2 and 3.1. was determined using chromatographic element analyzer, and using each of these pellet samples two boiler tests were carried out. The figure 6 shows the correlation between nitrogen content of pellets and the average concentration of NO in flue gases. In this case correlation is based on six points. Fuel nitrogen forms NO emissions mainly through fuel-NO mechanism. Results of experiments show that the NO average concentration is growing significantly with increasing nitrogen content in fuels [1,3].

Conclusions

In this paper have been analyzed the effect of pellet quality parameters and pellet chemical composition on emission of NO from a 15kW Latvian produced pellet boiler. From this analysis the following conclusions are possible:

1. Increasing supply air to the furnace – i.e. O_2 concentration - allow to reduce the average concentration of NO emissions. However this solution reduces as well as boiler efficiency
2. One of the typical nitrogen monoxide source is thermal NO formation mechanism, which depends on intensity of the flame temperature in the furnace. Increasing air supply allow reducing flue gas temperature and consequently NO emission
3. Increasing moisture content in the pellets allow to reduce the average concentration of NO emission. As well as this solution reduces boiler efficiency
4. When combusting biomass a significant amount of nitrogen monoxide is formed through fuel-NO mechanism. This is explained by the fact that biomass has a relatively high nitrogen content and the tests showed that NO emissions strongly increase with nitrogen content in the pellet samples
5. Additional tests and research is needed to identified multi correlations between the collected data. In particular for assessing the effect of pellet moisture and the relation ship between O2 content of flue gas, flue gas temperature and the ration of NO-emission in function as well as on Nitrogen content in the pellet sample.

References

1. T.Klason, X.S.Bai. Computational study of the combustion process and NO formation in small-scale wood pellet furnace // Fuel. – 86 (2007), P.1465 – 1474.
2. D.Blumberga, I.Veidenbergs. Slāpekļa oksīdu izmešu samazināšana. – Rīga: LU Ekoloģiskais centrs, 1992.
3. Emission characteristics of modern and old-type residential boiler fired with wood logs and wood pellets / L.S.Johansson, B.Leckner, L.Gustavsson, D.Cooper, C.Tullin, A.Potter // Atmospheric environment. – 2004. – [38]., P.4183 – 4195.

Aivars Žandeckis, Claudio Rochas, Dagnija Blumberga, Slāpekļa monoksīdu veidošānas mehānismu izpēte granulu degšānas procesā
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 noteikt slāpekļa monoksīda veidošānos ietekmējošus faktorus nelielas jaudas granulu apkures katlā. Kopumā tika veikti 11 katla testi atbilstoši standarta EN 303-5 metodikai. Rezultātu analīze tika balstīta uz korelācijas meklējumiem starp NO vidējo koncentrāciju un kurtuvē padodā gaisa daudzumu, dūmgāzu temperatūru, mitruma un slāpekļa saturu granulās.

Aivars Zandeckis, Claudio Rochas, Dagnija Blumberga, Research of formation of nitrogen monoxides during pellet combustion

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 determine the factors that influence formation of nitrogen monoxide in low power pellet boiler. Overall, 11 boiler tests were done according to methodology of standard EN 303-5. Analysis of results was based on search for a correlation between NO average concentration and air supply in the furnace chamber, flue gas temperature and moisture and nitrogen content in pellets.

Айварс Жандецкис, Клаудио Роцхас, Дагния Блумберга, Исследование образования моноксида азота в процессе горения гранул

Уменьшение изменений климата и использование возобновляемых энергоресурсов являются важными целями политики охраны окуружающей 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 выявление факторов, влияющих на образование моноксида азота в гранульном отопительном котле малой мощности. В сумме были проведены 11 тестов котла по методике стандарта EN 303-5. Анализ результатов был основан на поиске корреляции между моноксидом азота и количеством подаваемого в топку воздуха, температурой дыма, влажностью и содержанием азота в гранулах.