

EVALUATION OF FERMENTED WASTE ENERGETIC CHARACTERISTICS AND THE NUMERICAL MODELLING OF NITROGEN OXIDES CONCENTRATIONS DURING COMBUSTION

Violeta Cepanko¹, Pranas Baltrenas²

^{1,2}*Vilnius Gediminas technical university, Saulėtekio ave. 11, LT-10223 Vilnius, Lithuania.*
E-mails: ¹violeta.cepanko@vgtu.lt; ²pbalt@vgtu.lt

Abstract. The paper presents the numerical modelling methodology of separated gaseous pollutants concentrations assess and results obtained by comparison with the experiment values. Gaseous pollutants separate when the solid fuel, which is consisting of different types of, fermented (also another organic and municipal) waste, are burned. It was found a new formula to calculate the conversion factor of nitrogen, which is in fuel. Also it can be used to another organic types NO_x concentrations assess. The simulation results are presented applying the new values of conversion factors. The suggestion that the theoretical amount of air is proportional to the calorific value was used to check the known fuel species composition analyses data. The two equations are set by Least-squares method. It can be assessed in combustion air and combustion products theoretical quantities. Based on these additions can be determined not only fermented waste V_{oro}^f and V_d^f , but knowing only the calorific value of fuels and other fuels theoretical values. The prepared equation which presented in paper can be used to describe the dependence of nitrogen conversion in solid fuels from the nitrogen content. NO_x concentration values determined during *Gaska&Wandrasz* model differ, on average, by 12.7 % from values identified during investigations, except for those established for fermented grain substrate. The main assumption for the formation of larger inadequacies can be related with instability of fuel combustion that is preconditioned by the bulkiness, porosity or ash content of fuel along with other factors. More detained research on the physical characteristics of fuel is necessary to have this assumption confirmed.

Keywords: biofuel, combustion, fermented waste, heating value, modelling, nitrogen oxides.

1. Introduction

Direct combustion of biomass after biogas digestion has the potential for generating a valuable product while, at the same time, protecting the environment by absorbing the litter in an environmentally benign manner (Wandrasz and Wandrasz 2006).

The characterisation of certain biomass types as waste not only bears consequences for the applicable regulatory framework, but also for the EU's policy on renewable energy in general, one basic question being whether energy generated from waste should be regarded as renewable energy. The realization of technological processes with formed fuel components in associated thermal systems should be qualified by technical criteria, which means that elementary processes as well as factors of sustainable development, from a global viewpoint, must not be disturbed (Wandrasz and Wandrasz 2006).

Currently, research on biodegradable waste utilisation, especially after biogas recovery, has become increasingly relevant (Zigmontienė and Zuokaitė 2010; Čepanko and Baltrėnas 2007). One of priority research

areas, therefore, is the design of new technologies intended for the use of renewable, local and waste energy resources; moreover that the development of renewable and local energy resource (biofuel from biomass) production and use technologies is one of the key aims of the Lithuanian energy (Katinas *et al.* 2009; Šlančiauskas and Kalpokaitė 2006; Židonyte 2006; Stasiūnas 2007).

The scientist (Baltrėnas and Kvasauskas 2007; Baltrėnas and Kvasauskas 2009) found that the best possibilities of developing the utilisation of the organic waste are related with its use for energy recovery. Traditional biomass burning in stoves may be simple and unproblematic where energy production volumes are low and labour force is cheap (Stasiūnas 2007). Such method of energy production at large energy facilities requires high labour and energy costs (Denafas and Buinevičius 2008). With the aim of automating the process of biofuel burning, some countries of the European Union (Austria, Germany, Sweden, and others) have adopted technical standards of wood briquette and granule quality (Spadaro *et al.* 2000; Sahin 2011). In the meantime insufficiently research has been done on the composition and thermal

properties of solid biofuel recovered from fermented waste (Čepanko *et al.* 2010a; Čepanko *et al.* 2010b).

The idea for the conversion of segregated combustible components or combustible substances from technological processes into fuel is based on the following assumptions:

- substances of fuels have identified chemical properties and composition, that make components; and
- the combustion process of formed fuels is known (Buinevičius 2009; Raveendran *et al.* 1996; Wandrasz and Wandrasz 2006).

One of the ultimate goals of fire modelling is to predict flame spread and extinguishment over practical building materials and furnishings. In addition to individual solid and gas phase models, the coupling between the phases must be captured so that the burning rate is predicted rather than prescribed (Grønli and Melaaen 2000). Recent numerical studies¹ of the solid phase pyrolysis have used computational fluid dynamics (CFD) for the modelling of this coupling. These studies have shown that in small scale, where an external source of radiation is usually present, the effect of the flame feedback does not control or sustain the pyrolysis (Raveendran *et al.* 1996). However, at larger scales the flame feedback is likely to dominate the net heat flux, and correspondingly the overall burning rate. This presents a challenge to the

fire model, which must capture the essential dynamics at different scales (Yuan 1999).

The heat transfer and pyrolysis inside the wood material are modeled using the onedimensional model of (Grønli and Melaaen 2000), which was further developed by (Ritchie *et al.* 1997). The model is applied on each wood material surface cell of the computational domain. It describes the evaporation of moisture and the degradation of the virgin wood to gaseous fuel and char (Raveendran *et al.* 1996; Yang *et al.* 2004). The volatile gases are instantaneously released to the gas space.

In laminar flames, and at the molecular level within turbulent flames, the formation of NO_x can be attributed to three distinct chemical kinetic processes. The NO_x formed by these three processes is described as thermal NO_x, prompt NO_x, and fuel NO_x. Thermal NO_x is formed by the oxidation of atmospheric nitrogen present in the combustion air. Prompt NO_x is produced by high-speed reactions at the flame front, and fuel NO_x is produced by oxidation of nitrogen contained in the fuel (Buinevičius ir Puida 2005, Buinevičius 2009).

The key aim of this work was to carry out an evaluation of gaseous pollutant (NO_x) emissions from the process of incineration through the employment of a digital Gaska&Wandrasz model.

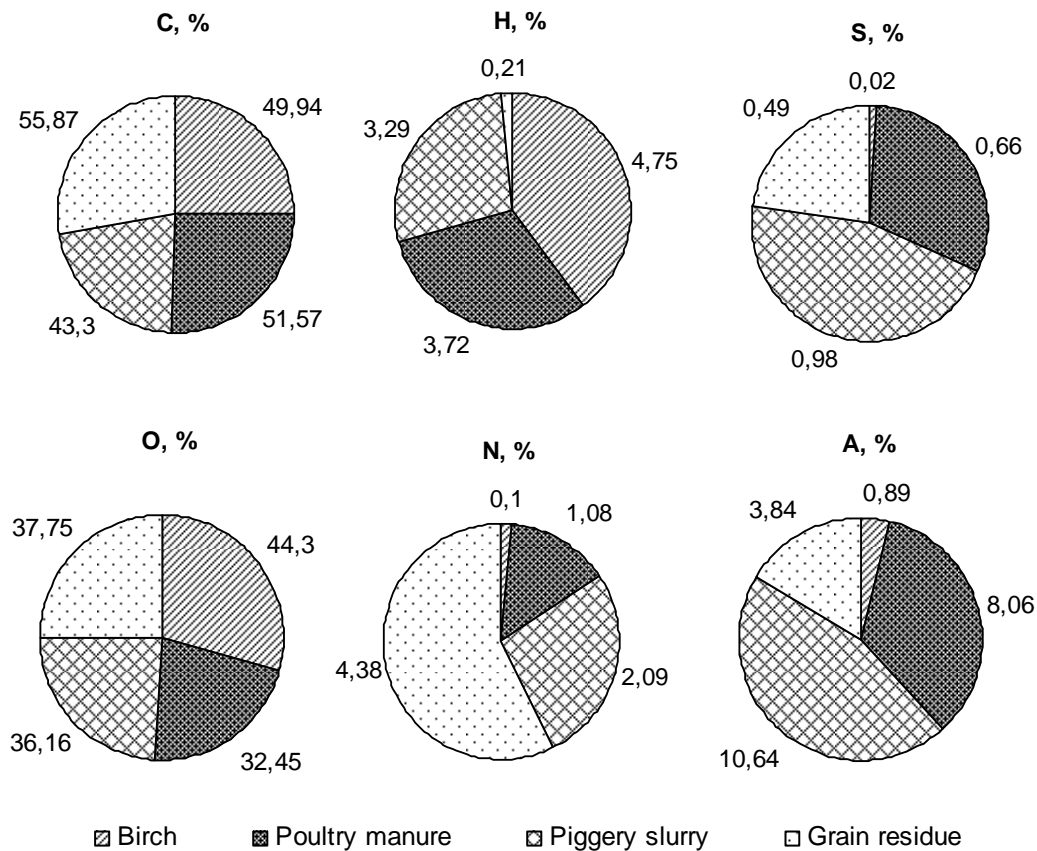


Fig 1. Date of the elemental composition of fermented waste (*C* – carbon content; *H* – hydrogen content; *S* – sulfur content; *O* – oxygen content; *N* – nitrogen content; *A* – ash content)

2. Elemental analysis of fermented waste and theoretical calorific value estimation

Elemental analysis of wood and fermented waste (poultry manure, piggery slurry and grain residue, Fig. 1) samples was determinate in Institute of Chemistry of Vilnius University in Department of materials structure laboratory using scanning electron microscopy. In this method membranes were sputter coated and imaged with a Zeiss EVO 50 XVP scanning electron microscope equipped with digital image acquisition. Average fiber diameter was determined from representative samples using NIH ImageTool (UTHSCSA version 3). All measurements were taken perpendicular to the long axis of electrospun fibers. Measurements were calibrated from size bars incorporated into the SEM images at the time of capture (Speiser *et al.* 2001).

The chemical elementary composition of the dry biomass of fermented waste differs from that of fossil fuel. The average elementary composition of the biomass' combustible part varies in the following ranges: 43.3–55.87 % for carbon, 0.21–4.75 % for hydrogen, 32.45–44.3 % for oxygen. In addition, around 0.02–0.98 % of sulphur and around 0.1–4.38 % of nitrogen was identified in the waste biomass. Subject to the conditions of treatment and preparation, the waste biomass also contains up to 0.2–0.75 % of chlorine (Čepanko *et al.* 2010b).

As research results showed, the highest contents of nitrogen were in the substrates of a mixture of swine manure and meat waste (at the ratio of 1:1) and grain reaching 9.80 and 4.38 % of a dry mass, respectively. In other substrates the content of this element was 2 to 3 times lower. The content of nitrogen in wood granules was much lower than that determined for waste and accounted for 0.1 % of a dry mass (Čepanko *et al.* 2010b).

As latest research show (Čepanko *et al.* 2008), fermented waste is characteristic of much higher ash content (3.84–18.95 %) than wood granules (0.89 %). This feature of the waste should be considered when designing incineration installations.

The models based on ultimate biomass analysis (Huang *et al.* 2008; Gaska and Wandrasz 2008; Demirbas 1997; Demirbas *et al.* 1996) which could be evaluated calorific values of fermented waste is:

Tillman (Eq. I)

$$\text{HHV} = 0.4373c - 1.6701 \quad (1)$$

Jenkins (Eq. II)

$$\text{HHV} = 0.4791c + 0.6676h + 0.0589o - 1.2077s - 8.42 \quad (2)$$

Grabosky and Bain (Eq. III)

$$\text{HHV} = 0.328c + 1.4306h - 0.0237n + 0.0929s - (1 - p/100)(40.11h/c) + 0.3466 \quad (3)$$

Wandrasz (Eq. IV)

$$\text{HHV} = 0.3491c + 1.1783h + 0.1005s - 0.1034o - 0.0151n - 0.0211p \quad (4)$$

Demirbas (Eq. V)

$$\text{HHV} = 0.335c + 1.423h - 0.154o - 0.145n \quad (5)$$

there HHV – higher heating value, MJ/kg; c – carbon content; h – hydrogen content; s – sulfur content; o – oxygen content; n – nitrogen content; p – phosphorus content (all in percentage).

Experimental results show the effect of moisture content can be accounted for by using the net heating value in which the latent heat of the moisture in the waste is subtracted from the higher heating value (Čepanko and Baltrėnas 2009).

Model patterns listed were fit with the experimental data by regression analysis using all sample data points (Huang *et al.* 2008; Gaska and Wandrasz 2008; Demirbas 1997; Demirbas *et al.* 1996). The method of least square, minimizing the error squared, was used to evaluate the adjustable parameters for each expression (Majumder 2008). To select the most appropriate correlation, the coefficient of determination (R^2) was mainly considered.

For models based on the ultimate analysis, the best fit was achieved by Eqs. (IV) with the R^2 of 0.9438. To sum up, the best universal correlation to represent the heating value of organic waste in terms of elemental analysis data would be Eq. (IV). Investigations shows that the value which was calculated by Eq. (IV) has fairly small discrepancies between the experimental values (Čepanko *et al.* 2008; Čepanko *et al.* 2010a).

Experimental results presented a large variety of the fermentable waste conditions. The compositions of biomass among fuel types are variable. The highest predicted HHV are from less than 18.4 KJ/kg to as high as almost 23.3 KJ/kg show the daff of grain witch carbon content was also the highest from other type of fermentable waste (Čepanko *et al.* 2008).

Based upon experimental data collected from literature (ECN laboratory data) ultimate analyses, the best results show coefficients of determination (R^2) of 0.9438 for the model of Wandrasz. The heating values obtained from the models of Demirbas ($R^2=0.9150$) and Milne ($R^2=0.9187$) was also in good agreement with that attained by theoretical value calculated with model of Wandrasz (Čepanko *et al.* 2010a).

The comparison was also made for different categories of waste from which the above correlations were derived and it was observed that irrespective of the fact whether a waste falls under the classification of sewage sludge, organic residue or grain, the values of average absolute and bias error with the present correlation are either minimum or comparable to minimum. It is observed that the average absolute error of Wandrasz and Demirbas for the entire spectrum of fuels considered herein are in the order of 2.07 and 1.09 %, respectively, while the bias error for the same correlations are found to be -2.07 and -1.09 %, respectively (Čepanko *et al.* 2008).

3. Evaluation of the air amount required for combustion and the generating theoretical quantity of fume

On the basis of the previous research findings (Čepanko *et al.* 2008, Čepanko *et al.* 2009), the dependencies (formulas 6 and 7) that can be used to evaluate the theoretical quantities of air and gas (V_{oro}^t and V_d^t) necessary for combustion of the fermented waste.

$$V_{oro}^t = 0,00026 \cdot Q + 0,05954 \quad (6)$$

$$V_d^t = 0,00029 \cdot Q + 0,04886 \quad (7)$$

where $LHV(Q) = Q_z^n$ is the lower heating value (Čepanko *et al.* 2010) that could be determined with formula:

$$Q_z^n (LHV) = 348 \cdot C^n + 939 \cdot H^n + 105 \cdot S_d^n + 63 \cdot N^n - 108 \cdot O^n - 25 \cdot W \quad (8)$$

where C^n is carbon content in fuel, H^n hydrogen content, S_d^n sulphur content, O^n oxygen content, N^n nitrogen content and W fuel moisture content.

Table 2. Combustion characteristics of fermented waste (poultry manure (2), swine manure (3), swine manure with meat waste at the ratio 1:2 (3a-3*), and grain substrate (4))

Sample Nr.	Name of waste	V_{oro}^t , m ³ /kg	V_d^t , m ³ /kg
2	Poultry manure	4.59	5.10
3	Swine manure	3.68	4.09
3a-3*	Swine manure/ meat waste (at the ratio of 1:2)	5.61	6.24
4	Grain	4.98	5.54

The values of these parameters determined for the fermented waste knowing only its calorific value (formula 8) are presented in Table 2.

4. Experimental investigations of fermented waste incineration and nitrogen oxides formation during combustion

The experiments of fermented waste dewatering and incineration were carried out in June and July 2008.

Incineration was carried out at the Kaunas University of Technology (KTU) Laboratory of Combustion Processes, in a solid fuel burning boiler with helical fuel supply to the incinerator with immovable grate (Fig. 2). This laboratory model of boiler could be used for evaluation of gaseous pollutant concentrations of high-power boilers. During the optimum conditions and complete fuel (wood) combustion, the concentration of gaseous pollutant errors was of up to 20 % (Čepanko *et al.* 2010b). To have uniform combustion the fermented waste from the fuel bunker was continuously supplied to the furnace, on oblique grate. To improve the combustibility of some substrates and maintain the process of combustion, sub-

strates were mixed up at different proportions with wood granules. The experimental incineration covered (Fig. 2): wood granules (1), poultry manure with wood granules at the ratio of 1:2 (2c), swine manure (3a) with meat waste, the ratio 1:1 (3b), and wood granules at the ratio of 1:2 (3c), grain substrate (4).

Fuel was combusted at a stable traction of 9–9.5 Pa in the incinerator and smooth air supply for combustion and by changing the frequency of fuel supply screw engine from 6 to 20 Hz. The concentrations of carbon monoxide and dioxide, sulphur dioxide, nitrogen oxides and oxygen in fume as well as fume temperature in the measurement places of concentrations were determined experimentally. Temperatures and gaseous component concentrations were determined with a mobile gas analyser (Čepanko *et al.* 2010b). The performed test of repeated experiments shows that the average square error of measurements of combustion gas concentrations in combustion products during waste incineration is no larger than 15 %. The experimental results were processed statistically by using the software package Statistical and presented with the reliability of $p=0.95$ (Krylovas *et al.* 2007).

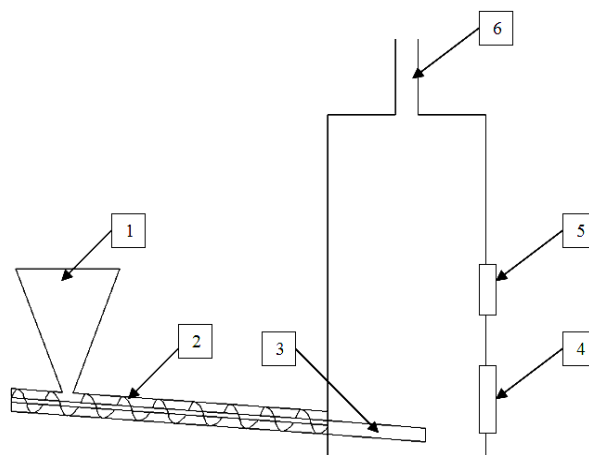


Fig 2. Scheme of sample incineration boiler with automatic fuel supply (1 – fuel bunker; 2 – fuel screw; 3 – immovable grate; 4 – service door; 5 – window to watch fuel combustion process; 6 – gaseous pollutant sampling place)

The incineration of fermented waste substrates included: poultry manure with wood granules at a ratio of 1:2, swine manure, swine manure with meat waste at a ratio of 1:1, swine manure with wood granules at a ratio of 1:2, and grain substrate (Table 3).

It is determined experimentally that fuel humidity did not have a significant impact on a fuel combustion process as it varied within minor limits (1.31–2.54 %).

In summary of the investigations of fermented waste incineration in a low-capacity stand it can be stated that the maximum temperatures of combustion products at a boiler outlet were achieved when burning wood granules and grain reaching 177.7 °C and 147.8 °C, respectively. In other cases temperatures were lower because of lower calorific value of the waste.

Table 1. Comparison of nitrogen oxide concentration in smoke during incineration of fermented waste, measured during experimental incineration with normative data during combustion of fuel and waste

Sample Nr.	NO _x (O ₂ =6%), mg/kg	NO _x (O ₂ =11%), mg/kg	Requirements for NO _x (mg/kg) in LAND 43-2001*	Requirements for NO _x (mg/kg) in Environmental requirements for incineration of the waste**	Exceeding *	Exceeding **
1a	664	442	650	350	0.8	1.3
3c	1891	1260			2.2	3.6
4a	4682	3121			8.0	8.9
4b	4178	2785			4.8	8.0
4c	1331	887			1.5	2.5
5a	5084	3389			4.1	9.7

Comparison of NO_{x, min} and NO_{x, aver} concentrations with the permissible limit values, determined for the biomass pursuant to LAND 43-2001, show that exceedances reached 1.2–6.5 times and 2.0–7.8 times (Table 3), and according to the environmental requirements for waste incineration these exceedances varied from 1.5 to 8.0 and from 2.5 to 9.7 times.

It is established that high concentrations of NO_x are predetermined by a high content of nitrogen compounds in the fermented waste. The comparative tests allow a conclusion that NO_x concentration in the products of combustion is predetermined by fuel's NO_x. When designing industrial installations for fermented waste incineration, measures aimed at reducing NO_x generation or smoke treatment facilities have to be envisaged (Buinevičius 2009).

During wood granule burning, fluctuations of nitric oxide concentrations were not significant varying from 264 to 322 mg/m³. The fact that no strong dependence of NO_x on the oxygen concentration was determined shows that the thermal constituent of NO_x is insignificant and NO_x of fuel is prevailing.

During fermented poultry manure incineration, NO_x concentration varies between 476 and 671 mg/m³. Like in the case of wood burning no strong dependence, characteristic of the thermal NO_x, on oxygen concentration was observed (Kirubakaran *et al.* 2007). In this case, too, NO_x constituent of fuel is prevailing whereas the average NO_x level is higher by around 300 mg/m³ than in the case of incinerating wood granules.

It is determined experimentally that swine manure waste burnt slowly and heavily. This is also confirmed by a low temperature of combustion products. The increased air amount was supplied for combustion in order the dynamic flow would also perform the function of ash removal from the combustion zone. Rather low concentrations of NO_x obtained as a result cannot be considered as the typical ones as no quality combustion occurred. However, incinerating pure swine manure in a heated furnace of a low capacity installation would be possible (Buinevičius and Puida 2005; Buinevičius 2009).

In this case the average NO_x concentration is higher by around 240 mg/m³ compared of the swine manure with wood granules to burning wood alone. A high leap in CO concentration, from 1058 to 3892 ppm, actually had no effect on NO_x concentration. Such an effect would have

been present if NO_x was composed of thermal NO_x. Thus, these experiments confirm the fact that NO_x concentration during these tests was predetermined by the content of nitrogen in the material being incinerated (Buinevičius 2009).

Big emission of nitrogen oxides was determined during grain burning, i.e. similarly as in the case of incinerating swine manure with meat waste. NO_x concentrations changed from 751 to 1002 mg/m³. Due to a very fine fractional composition, burning of this type of waste was disorderly. When fuel accesses the zone of combustion, volatile substances burn up quickly and the combustion of the remaining part of fuel is protracted (Čepanko *et al.* 2010b). High instability of combustion was recorded at the concentration of O₂ of around 18 %. Atypical changing tendencies of NO_x and CO concentrations were recorded as the concentrations of both the components are increasing and decreasing at the same time. This can be explained by the flashes of more rapid combustibility of fuel as the temperature of combustion products would also increase (Kavaliauskas 2005; Buinevičius 2009).

5. Evaluation of conversion factor

To the evaluation the conversion factor K_N was needed the theoretical amount of combustion air V_{oro}^t and the theoretical volume of combustion products V_d^t , which can be calculated by (6) and (7) equations and which depending on the fuel lower calorific value (Čepanko *et al.* 2010b):

$$K_N = (N^i \text{ in the } NO_x \text{ emission} / N^i \text{ in fuel}) * 100 \quad (9)$$

where K_N is nitrogen conversion factor in %, N^i is nitrogen content, g.

It is estimated that the fuel nitrogen conversion to NO_x ratio values of fermented waste generated ranging from 0.0433 to around 0.242. By comparison, in the schedule was delayed K_N values obtained by experiment and by (Čepanko *et al.* 2010b) authors and was determined trend (10).

Analysis of the survey results showed that under totally different nitrogen sources and different types of fuel combustion, fuel nitrogen conversion to NO_x can be roughly estimated by the equation (when $p = 0.05$ and $R^2 = 0.8344$):

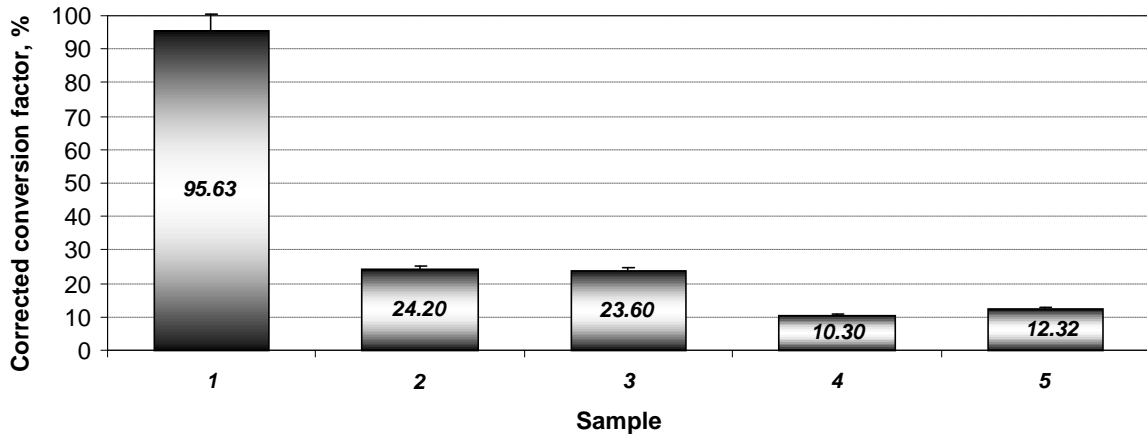


Fig 3. The conversion factor value of NO_x from solid fuels nitrogen (1 – wood pellets, 2 – fruit/vegetable waste, 3 – poultry manure, 4 – pig manure, 5 – grain)

$$K_N = 14.941 \cdot N^{(-0.854)} \quad (10)$$

So great statistical error (8.65 %), given the (5) trend, it makes the difference (from 7 % to 40 %) between estimated and real emission of NO_x. To avoid such a large discrepancy the new trend must be corrected (statistical error should be at least 2 %) (Krylovas *et al.* 2007).

Applying the new formula the conversion factors values of nitrogen to NO_x emission is: for vegetable/fruit waste – 0.2247; for poultry manure – 0.1433, for pig manure – 0.0816 and grain residue – 0.0433.

Dependence (10) formula is universal for many kinds of waste and independent of the temperature of combustion. Calculating a conversion factor taken into account indirectly the amount of oxygen used during combustion when $\alpha=1.4$, i.e. O₂=6 %, and directly in the calculation of the theoretical value of the theoretical amount of combustion air (V_{oro}') and the theoretical volume of combustion products (V_d').

6. Numerical simulation results of nitrogen oxides formation, during combustion

The optimization algorithm of Gaska&Wandrasz model is based on a linear programming problem taking advantage of a modified simplex method. This algorithm is distinct from a classic algorithm for it allows us to consider the changes of decision variables of the task in permissible space, defined on the basis of careful analysis of technical conditions, as well as ecological and economic ones which parameters of formed fuel must satisfy in case of their use in thermal associated processes. The presented mathematical model is a base for object-oriented numerical models and expert systems of assistance in decision processes (Gaska and Wandrasz 2008).

Stoichiometric equations of the fuel combustion process were formed with the assumption that in the production of the process there is a lack of solid, liquid or

gaseous combustible components (complete combustion) and there is no dissociation of CO₂ and H₂O products.

Balance of elements (Szargut 2003):

$$C: n_C' = n_{CO_2}'' \quad (11)$$

$$S: n_S' = n_{SO_2}'' \quad (12)$$

$$H_2: n_{H_2}' + n_a' X_{za} + n_{H_2O}' = n_{H_2O}'' + \frac{1}{2} n_{HCl}'' \quad (13)$$

$$O_2: n_{O_2}' + 0.21n_a' + \frac{1}{2}n_{H_2O}' + \frac{1}{2}n_a' X_{za} = n_{O_2}'' + n_{CO_2}'' + n_{SO_2}'' + \frac{1}{2}n_{H_2O}'' \quad (14)$$

$$N_2: 0.79n_a' + n_{N_2}' = n_{N_2}'' \quad (15)$$

$$Cl_2: n_{Cl_2}' = \frac{1}{2}n_{HCl}'' \quad (16)$$

Molar composition of dry exhaust gas:

$$[CO_2] = \frac{n_{CO_2}''}{n_{ss}} \quad (17)$$

$$[SO_2] = \frac{n_{SO_2}''}{n_{ss}} \quad (18)$$

$$[O_2] = \frac{n_{O_2}''}{n_{ss}} \quad (19)$$

$$[N_2] = \frac{n_{N_2}''}{n_{ss}} \quad (20)$$

$$[HCl] = \frac{n_{HCl}''}{n_{ss}} \quad (21)$$

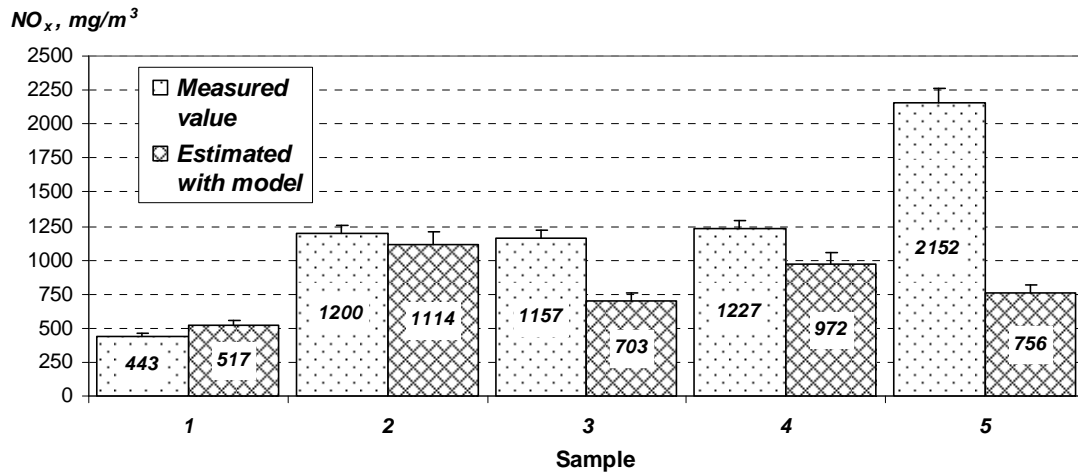


Fig 4. Comparison of nitric oxide concentrations obtained by the experiment and of simulation (1 – wood pellets, 2 – fruit/vegetable waste, 3 – poultry manure, 4 – pig manure, 5 – grain)

$$[H_2O] = \frac{n_{H_2O}}{n_{ss}} = X_{Z_{H_2O}} \quad (22)$$

The calculation procedures outlined above are embodied in a numerical model programmed in the Pascal (Delphi 5.0) high-level object-oriented language (Dumnicki *et al.* 1998), with a graphical Windows-based user interface. In order to verify our numerical model, and to validate (Retsgaard and Henriksen 2004) its computer code, we simulated test problems and compared our results with the analytical solutions.

Validation of the model was carried out with the following assumptions: for the fuel formed from fermented waste of the chemical composition (Fig. 1); optimization constraints imposed on fuel formation process are used (Table 2).

Results of laboratory combustion tests of and modelled values, as well as results of computer simulations, are presented in Fig. 4.

The results obtained when using the *Gaska & Wandrasz* model for assessing NO_x concentration contents and by applying the adjusted coefficients of nitrogen conversion differ from the experimental results by: 14 % for wood granules, 7 % for fruit/vegetable waste, 39 % for poultry manure, 21 % for swine manure (Fig. 4).

NO_x concentration values determined during modelling differ, on average, by 12.7 % from values identified during investigations, except for those established for fermented grain substrate (Čepanko 2010). The main assumption for the formation of larger inadequacies can be related with instability of fuel combustion that is preconditioned by the bulkiness, porosity or ash content of fuel along with other factors (Grønli and Melaaen 2000; Kirubakaran *et al.* 2009). More detained research on the physical characteristics of fuel is necessary to have this assumption confirmed.

The assessment of substrate grain results show that the average error of modelled and experimental estimated values was much than 65 %. The basic assumption for these phenomenon explain could be related with larger

discrepancies which led the fuel mass losses in the whole combustion process was not constant (Babilius *et al.* 2008; Demirbas 2010). It's also could be related with the grain porosity and with high burning rate and low ash content (Kavaliauskas 2005; Buinevičius and Melkunas 2008; Wandrasz and Wandrasz 2006). To confirm the assumption it is necessary further study of the fuel physical and chemical properties.

7. Conclusions

1. Based upon experimental data collected from literature (ECN laboratory data) ultimate analyses, the best results show coefficients of determination (R^2) of 0.9438 for the model (formula) of Wandrasz. The heating values obtained from the models of Demirbas ($R^2=0.9150$) and Milne ($R^2=0.9187$) was also in good agreement with that attained by theoretical value calculated with model of Wandrasz.
2. The results obtained when using the *Gaska & Wandrasz* model for assessing NO_x concentration contents and by applying the adjusted coefficients of nitrogen conversion differ from the experimental results by: 14 % for wood granules, 7 % for fruit/vegetable waste, 39 % for poultry manure, 21 % for swine manure.
3. As a result of computer simulations with *Gaska & Wandrasz* model and laboratory experiments, the model gives the results that are very close to the obtained from the real process. NO_x concentration values determined during modelling differ, on average, by 12.7 % from values identified during investigations, except for those established for fermented grain substrate.

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