RESEARCH ON A BOILER FURNACE MODULE EFFECTIVENESS WORKING ON SMALL FRACTURE WASTES

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ДОСЛІДЖЕННЯ ЕФЕКТИВНОСТІ РОБОТИ ТОПКОВОГО ПРИСТРОЮ КОТЛОАГРЕГАТУ НА ПАЛИВІ З ДРІБНОЗЕРНИСТИХ ВІДХОДІВ

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ABSTRACT

A method of defining an optimal blowing mode for the boiler when burning agricultural plant residues with varying moisture content, by measuring flue gases temperature was proposed. A multifactor experiment was planned to interconnect the above-mentioned parameters. A tuning chart for the boiler was built based on the results. It was defined that maximum flue gases temperature is an indicator of optimal air supply, i.e. flue gases temperature is an estimate indicator of combustion completeness. As a result of researching regime parameters when burning different plant residue mixtures and analysing received response surfaces, the parameters for maximized heat productivity were obtained.

РЕЗЮМЕ

Представлено метод визначення оптимальних технологічних режимів дуття в процесі експлуатації котлоагрегату при спалюванні рослинних залишків аграрного походження змінної вологості дослідженням температури димових газів. Сплановааний багатофакторний експеримент, який пов'язує означені вище параметри, за його результатами побудовані регулювальні характеристики котлоагрегату. Встановлено, що найвищі значення температури димових газів є показником оптимального значення питомих витрат повітря, тобто температура димових газів є оціночним показником горіння. В результаті дослідження режимних параметрів спалювання складних сумішей рослинних відходів та аналізу отриманих поверхонь відгуку отримано режими, що забезпечують їх спалювання з найбільшою тепловіддачею.

INTRODUCTION

One of the ways of integrated use of bioenergy conversion technologies in agroecosystems is burning plant residues in boilers *(Golub et al., 2017; Geletuha and Zheleznaya, 2014; Roy and Dias, 2017; Sippula et al., 2017).*

Combustion – is a complex physicochemical process, the basis of which is a quick oxidization process with intense energy releasing via heat and light radiation *(Cao et al., 2017; Didura and Struchaev, 2008; Lavrenuk et al., 2014; Nussbaumer, 2003).* To support continuous and long-lasting combustion in a furnace one has to provide such conditions: permanent fuel feeding and air blowing and their extensive mixing with each other; proper temperature needed for ignition and constant intensive burning; continuous combustion products extraction *(Branco and Costa, 2017; Porteiro et al., 2006).*

When burning solid fuels several stages can be separated: heating fresh fuel portions; humidity evaporation; volatiles sublimation and coke formation; volatile and coke combustion; ash formation. *(Yin et al., 2008).* Herewith while increasing fuel layer height, an oxidant concentration in combustion gases goes down (*Didura and Struchaev, 2008; Lavrenuk et al., 2014*).

When burning plant raw material in thermotechnical equipment (a boiler) the thermal balance looks like the following (*Stepanov et al., 2011)*:

$$Q_{LCV} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6, \tag{1}$$

where Q_{LCV} is lower calorific value of a fuel, MJ/kg.

Dividing both parts of (1) by Q_{LCV} and multiplying by 100% we receive a boiler thermal balance in %:

$$100 = q_1 + q_2 + q_3 + q_4 + q_5 + q_6, \tag{2}$$

where q_1 – is useful thermal energy; q_2 – thermal loses with flue gases; q_3 – loses from chemical combustion incompleteness; q_4 – loses from mechanical combustion incompleteness; q_5 – loses through the outer shell into environment; q_6 – loses with the heat of the ash.

A characteristic of furnace, as a part of thermotechnical equipment, effectiveness is a combustible components combustion completeness. Therefore, the furnace coefficient of performance (CoP), when q_5 and q_6 are constant, is calculated like *(Carvalho et al., 2013; Kær, 2004; Lerkkasemsan, 2017):*

$$\eta = 1 - \frac{(q_3 + q_4)}{100}. \tag{3}$$

Indicator q_3 is conditioned by incomplete combustion of such fuel components as CO, CH_4 and H_2, the calorific value of which is evacuated from furnace module with flue gases in a chemically bonded state.

A chemical incompleteness of combustion is conditioned by multiple phenomenon: a lack of air, supplied into combustion chamber of furnace module; unsatisfactory mixing of fuel and air in the chamber; low temperature in boiler`s combustion chamber, which can't provide persistent combustion *(Bhuiyan and Naser, 2015; Karim and Naser, 2014; Masud et al., 2016)*. Indicator q_3 is going low while excess air coefficient is going up but to a certain extent, which is explained as when oxidant concentration in combustion zone of gaseous fuel components, which are extracted in gas producing process, rises, a combustion reaction runs more completely. For modern boiler designs q_3 can reach 3-5%, but even despite its little value, loses of fuel combustion incompleteness are significant (*Bhuiyan and Naser, 2015; Van Der Lans et al., 2000)*.

Indicator q_4 depends on loses connected with: fuel particles extraction with flue gases; fuel particles falling through the grates to ashtray; part of fuel carbon is not burning out and is extracted with ash (*Bhuiyan and Naser, 2015; Lavrenuk et al., 2014; Stepanov et al., 2011)*. The loses of q_4 raise while air excess coefficient α deviate from optimal value *(Tóth et al., 2017)*. While α is growing, q_4 is going low because of fuel and air mixing intensification but to a certain extent, with the further α growing q_4 began growing up because of fuel particles extraction from combustion zone intensification. Summing loses in combustion chamber for different α values we can determine optimal α value, which responds to minimal loses *(Kær, 2004; Porteiro et al., 2009; Ström and Thunman, 2013).*

As it is known α - is a real quantity of air, needed for complete combustion of fuel, to theoretical quantity, Q_{theor}, ratio. The Q_{theor} value is calculated from combustion equation provided that we know fuel elementary composition. Elementary composition is well known for traditional fuels (gas, petrol, fuel oil etc.), but considering fuels from agricultural plant raw material, it is determined only for few of them. For the fuels the elementary composition of which is unknown (buckwheat husk, millet husk), it is impossible to calculate theoretical air supply, as well as α, that is why when calculating oxidant supply for such fuels a specific air supply $Q_{specific}$ instead of α is used. It tells how much air is needed for the most complete burning of 1 kg of fuel. We must admit that the only way of determining $Q_{specific}$ is experimental.

$$Q_{specific} = \alpha \cdot Q_{theor}. \tag{4}$$

where Q_{theor} – is theoretical air quantity needed for complete burning of 1 kg of fuel, m^3/kg.

Furnace module always works in pair with some thermotechnical equipment (boiler, heat producer etc.), that is why when burning fuel in furnace module the requirements of that equipment must be taken into account.

Heat which is transferred from/to any caloric media by means of thermotechnical equipment is transferred by radiation and convection:

$$Q = Q_{rad} + Q_{conv}. \tag{5}$$

Heat flux for radiation heat exchange is defined by (*Lavrenuk et al., 2014; Stepanov et al., 2011):*

$$Q_{rad} = \frac{C_0}{\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon} - 1} \left[\frac{\varepsilon}{\varepsilon_r} \left(\frac{T}{100} \right)^4 - \left(\frac{T_r}{100} \right)^4 \right] \cdot F_1, \tag{6}$$

where C_0 – black body radiation coefficient, W/(m^2·K^4); T – flue gases absolute temperature, °K; ε_w –wall blackness grade, T_r – rays acceptor absolute temperature, °K; ε, ε_r – gases blackness grade for temperature T and T_r; F_1 – ray acceptor surface area, m^2. Convectional heat flux is defined by:

$$Q_{conv} = k \cdot \Delta T \cdot F_2, \tag{7}$$

where k – heat transfer coefficient, W/(m$^2 \cdot {}^0$K); $\Delta T = T - T_{c.m.}$ – temperature difference between flue gases and caloric media heated by thermotechnical equipment, °K; F_2 – convection heat exchanger surface area, m^2.

The (6) and (7) shows that in order to raise quantity of useful heat, which is transferred through thermotechnical equipment, flue gases temperature should be raised, while other conditions being constant. The ratio for flue gases temperature is the following (*Stepanov et al., 2011)*:

$$T=\frac{Q_{LCV}\cdot\eta_f+q_{air}+q_{fuel}}{Q_{RO_2}\cdot c_{CO_2}+Q_{N_2}\cdot c_{N_2}+Q_{H_2O}\cdot c_{H_2O}+Q_{theor}(\alpha-1)\cdot c_{air}}, \tag{8}$$

where Q_{LCV} – fuel lower calorific value, kJ/kg; q_{air} – heat evacuated with air, kJ/kg; q_{fuel} – heat evacuated with fuel, kJ/kg; Q_{RO2}, Q_{N2}, Q_{H2O} – combustion products volumes, m^3/kg; c_{CO2}, c_{N2}, c_{H2O} – combustion products heat capacity for mean temperature *0* to *T* °C, kJ/(m^3·°K); $Q_{theor}(\alpha\text{-}1)$ – excessive air volume, m^3/kg; c_{air} – air heat capacity for mean temperature *0* to T_{air} °C, kJ/(m^3·°K).

Considering (4) equation (8) becomes:

$$T=\frac{Q_{LCV}\cdot\eta_f+q_{air}+q_{fuel}}{Q_{RO_2}\cdot c_{CO_2}+Q_{N_2}\cdot c_{N_2}+Q_{H_2O}\cdot c_{H_2O}+(Q_{specific}-Q_{theor})\cdot c_{air}}. \tag{9}$$

Thus, the furnace module CoP, which is the function of α ($\eta=f(\alpha)$), considering $Q_{specific}$ is constant for this fuel, will be determined as:

$$\eta=f(Q_{specific}) \tag{10}$$

From (9) considering (10) we draw the conclusion that, while other conditions are constant, flue gases temperature on the output of furnace module depends on specific air supply. Therefore, maximum flue gases temperature value is an indicator of optimal specific air supply value, i.e. flue gases temperature is an indirect indicator of combustion process quality.

Since we can’t define specific air supply optimal value theoretically – then the only simple and reliable method is the experiment.

The main requirement for the furnace module is providing maximum fuel calorific value, which, in turn, depends on air quantity supplied for combustion. Air supply is calculated with stoichiometric combustion equations which determine minimal air quantity needed to complete combustion of 1 kg of fuel providing that the entire oxygen in the air will react with fuel combustible components. In real conditions, real air quantity supplied for combustion process is always more than theoretically defined, because of imperfect air and fuel mixing and technical imperfection *(Bhuiyan and Naser, 2015; Cao and Li, 2017; Carvalho et al., 2013)*.

So, the less is the value of specific air supply provided complete fuel combustion the more perfect the combustion process is *(Kiselev, 1971; Nussbaumer, 2003)*. Lowering specific air supply raises furnace module CoP and lowers air blowers’ actuators consumption. Further lowering, to less than optimal, leads to fuel under burning and lowers the economic effect of thermotechnical equipment *(Melnichuk et al., 2011).*

The research defines experimentally specific air supply for optimal combustion of the buckwheat husk and millet husk. According to theoretical research while raising air supply, flue gases temperature raises, at first, because of lowering of chemical and mechanical under burning, but then, after certain value, lowers because of raising of unburned fuel particles evacuation and flue gases dilution by excessive air *(Stepanov et al., 2011; Van Der Lans et al., 2000).* So, the highest flue gases temperature on the output of furnace module let us talk about the highest combustion completeness, and that correspondent specific air supply is optimal for this type of fuel.

Therefore, the agenda of the research is to develop a method for defining optimal combustion modes for biomass of an arbitrary chemical and fractional composition, by means of multifactor experiment and received data processing. To check effectiveness of this method, that is oriented for usage in small farming without engagement of an outside specialist.

MATERIALS AND METHODS

Experiments were made on boiler designed in NUBIP of Ukraine (fig.1) with laboratory measuring equipment of NUBIP of Ukraine and Institute of Gas NAS of Ukraine according to the accepted methods and branch standards *(DSTU 3581-97).*

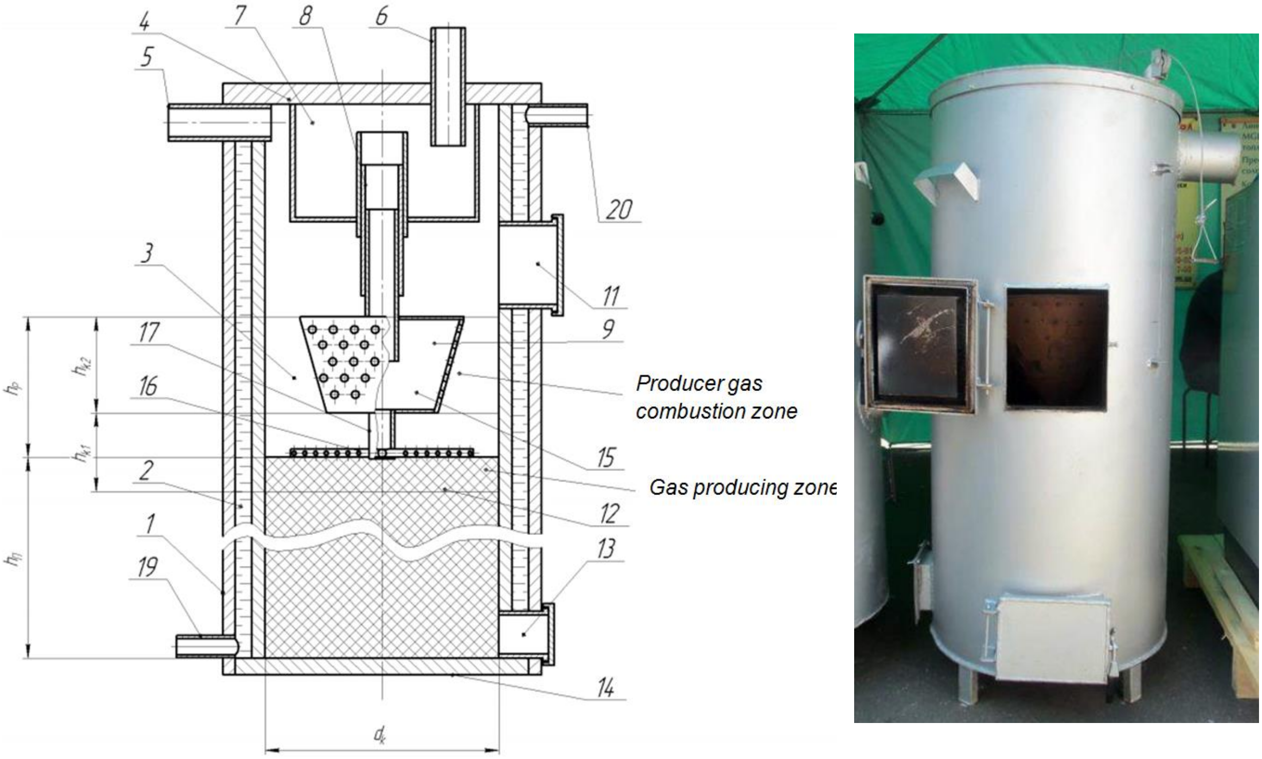


Fig. 1 – Boiler for straw, general view *(Kukharets, 2014)*

1 – outer shell; 2 – cavity; 3 – combustion chamber; 4 – lid; 5 – combustion product evacuation pipe; 6 – air supply pipe, 7 – intermediate capacity; 8 – guider; 9 – air diffuser; 10 – holes, 11 – doors for fuel; 12 – fuel; 13 – doors for ash; 14 – the bottom; 15 – air diffuser upper section; 16 – air diffuser lower section; 17,18 – pipe parts 19 –cold water supply pipe; 20 – hot water evacuation pipe; d_K *– boiler diameter;* $h_П$ *– fuel layer height;* h_p *– air diffuser height;* h_{K1} *– gas producing area height;* h_{K2} *– producer gas combustion area height*

Multifactor experiment *(Adler, 1976; Melnikov et al., 1980)* is about mutual influence of such factors as: flue gases temperature, air supply for the initial fuel combustion, producer gas combustion air supply, fuel mixture moisture content.

Experiment was held for different kind of mixtures. Mixture 1 – 50% buckwheat husk + 50% millet husk; mixture 2 – 20% chopped straw + 40% chopped sunflower disks + 40% sunflower husk.

Choosing variation intervals, we were thinking as follows. Total air supply was defined for nominal furnace module productivity based on the manufacturer`s recommendation for approximate calculations – 0.01846 m^3/s air supply for boiler nominal productivity of 50 kW (working heat productivity is 37.5 kW) *(Kiselev, 1971),* for the agricultural plant wastes with lower calorific value of 13.4 – 16.5 MJ/kg *(Kiselev, 1971; Roy and Dias, 2017).*

So, the total air supply will be (considering air excess coefficient recommended for boilers of spherical type α=1,3): max – 80 m^3/h, min – 50 m^3/h. Thus, multifactor experiment planning needs three levels and equal intervals we assume: 50, 65 та 80 m^3/h. Fuel moisture content variation levels were 10%, 25%, 40% *(Geletuha and Zheleznaya, 2014).* Variation levels of above-mentioned factors are given in table 1.

Table 1

Variable factors and limits of their variation for defining the combustion process technological parameters

Factor variation level	Fuel moisture content W, %	Fuel air supply Q_{air}, m^3/h	Producer gas air supply Q_{pg}, m^3/h
	X_1	X_2	X_3
Lower level (-)	10	11	39
Middle level (0)	25	14	51
Upper level (+)	40	17	63

Factors encoding: X_1=W, X_2=Q_{air}, X_3=Q_{pg}.

To reduce the number of experiments and obtain the regression equation, the mathematical method of the experiment planning based on Box-Behnken quadric plan *(Adler, 1976; Melnikov et al., 1980)* was used.

Planning stage included the following steps: factor encoding, scheduling, randomization tests, implementation plan of the experiment, testing the reproducibility of the experiments, calculation of regression coefficients, assessment of regression coefficients significance and test model adequacy.

The experiment consisted in 15 tests at threefold repetition in each of them.

Main measuring equipment were: fuel quantity Q_{fuel} (kg) was measured on technical scales VLR-1 (ВЛР-1) GOST 11219-71 (error 0,1%); air supply for fuel Q_{air} (m^3/h) and for producer gas Q_{pg} (m^3/h) was measured with differential pitot-static tube with micro manometer DSP-160-M1 (ДСП-160-М1) (error 0.025%) ТУ 25-7310.0063 (technical conditions of Ukraine); flue gases temperature T (^{0}C) was measured with a K-type thermocouple paired with EPP-093M3 (ЄПП-09М3) (error 1%); time τ (c) was measured with a mechanical stopwatch СОСпр-25-2-000±4 (error 0.02%) GOST 5072-79.

RESULTS

As a result of laboratory experiments and statistical computation a heat productivity data array was obtained; it is given in table 2.

Table 2

Planning matrix of a multifactor experiment for determining combustion parameters for two mixtures

№	Experiment planning method				Mixture 1							Mixture 2						
	X_0	X_1	X_2	X_3	T_1	T_2	T_3	T_{med}	$T_{med.com}$	$(T_{med} - T_{med.com})$	$(T_{med} - T_{med.com})^2$	T_1	T_2	T_3	T_{med}	$T_{med.com}$	$(T_{med} - T_{med.com})$	$(T_{med} - T_{med.com})^2$
1	+	+	+	0	340	335	338	337.5	341.1	-3.6	12.96	496	478	484	486	492.3	-6.2	38.69
2	+	+	–	0	339	335	188	287.2	315.4	-28.3	800.89	474	462	471	469	472.4	-3.4	11.70
3	+	–	+	0	376	373	376	374.7	346.4	28.2	795.24	496	496	508	500	496.4	3.4	11.70
4	+	–	–	0	371	368	369	369.0	365.4	3.6	12.96	492	486	479	485	479.3	6.2	38.69
5	+	0	0	0	389	390	388	388.8	390.8	-1.9	3.61	517	529	513	520	521.6	-2.0	3.88
6	+	+	0	+	334	325	332	330.0	331.4	-1.4	1.96	488	480	493	487	491.8	-4.7	22.28
7	+	+	0	–	365	371	370	368.5	359.1	9.4	88.36	489	492	512	498	498.2	-0.6	0.32
8	+	–	0	+	378	377	376	376.5	385.9	-9.4	88.36	493	511	517	507	506.5	0.6	0.32
9	+	–	0	–	365	359	360	361.2	359.8	1.4	1.96	488	507	503	499	494.6	4.7	22.28
10	+	0	0	0	388	385	388	386.8	390.8	-3.9	15.21	524	522	521	522	521.6	0.6	0.36
11	+	0	+	+	375	378	370	374.2	368.6	5.6	31.36	499	514	495	503	501.2	1.6	2.46
12	+	0	+	–	375	370	373	372.5	377.7	-5.2	27.04	504	502	500	502	504.2	-2.6	6.71
13	+	0	–	+	379	380	378	378.7	373.5	5.2	27.04	486	496	491	491	488.5	2.6	6.71
14	+	0	–	–	363	359	360	360.5	366.1	-5.6	31.36	483	473	479	478	479.9	-1.6	2.46
15	+	0	0	0	395	398	398	396.7	390.8	5.9	34.81	522	523	523	523	521.6	1.4	1.90
Regression coefficients:					$b_0=390.78$; $b_1=-13.81$; $b_2=1.688$; $b_3=-0.416$; $b_{12}=11.17$; $b_{13}=-13.46$; $b_{23}=-4.125$; $b_{11}=-30.55$; $b_{22}=-18.14$; $b_{33}=-1.18$							$b_0=521.61$; $b_1=-2.759$; $b_2=9.25$; $b_3=1.394$; $b_{12}=0.67$; $b_{13}=-4.552$; $b_{23}=-2.9$; $b_{11}=-16.1$; $b_{22}=-20.42$; $b_{33}=-7.757$						

Received data was processed according to multifactor experiment planning method, with making polynomial regressions of flue gases temperature on factors which influence combustion process.

Experiment results were processed using the software "Statistica". Homogeneity of variances was tested by the Cochrane criterion. Since $G^{com}=6.67<G^{tabl}(0.05;\ 15;\ 2)=19.3$ – for mixture 1 and $G^{com}=8.87<G^{tabl}(0.05;\ 15;\ 2)=19.3$ – for mixture 2, the process is reproduced. When we determined the confidence intervals for regression coefficients, the Student test was used, the tabulated value of which at a 5% level of significance and the number of degrees of freedom of experiment variance reproducibility $f_1=2$ was $t=4.3$ (*Melnikov et al., 1980*). The significance of regression coefficients was tested according to the established confidence intervals and covariance. As a result, the regression equation had the form:

- for mixture 1:

$$T=390.78-13.81\cdot X_1+1.69\cdot X_2-0.42\cdot X_3+11.17\cdot X_1\cdot X_2-13.46\cdot X_1\cdot X_3-4.13\cdot X_2\cdot X_3-30.55\cdot X_1^2-18.14\cdot X_2^2-1.18\cdot X_3^2 \quad (11)$$

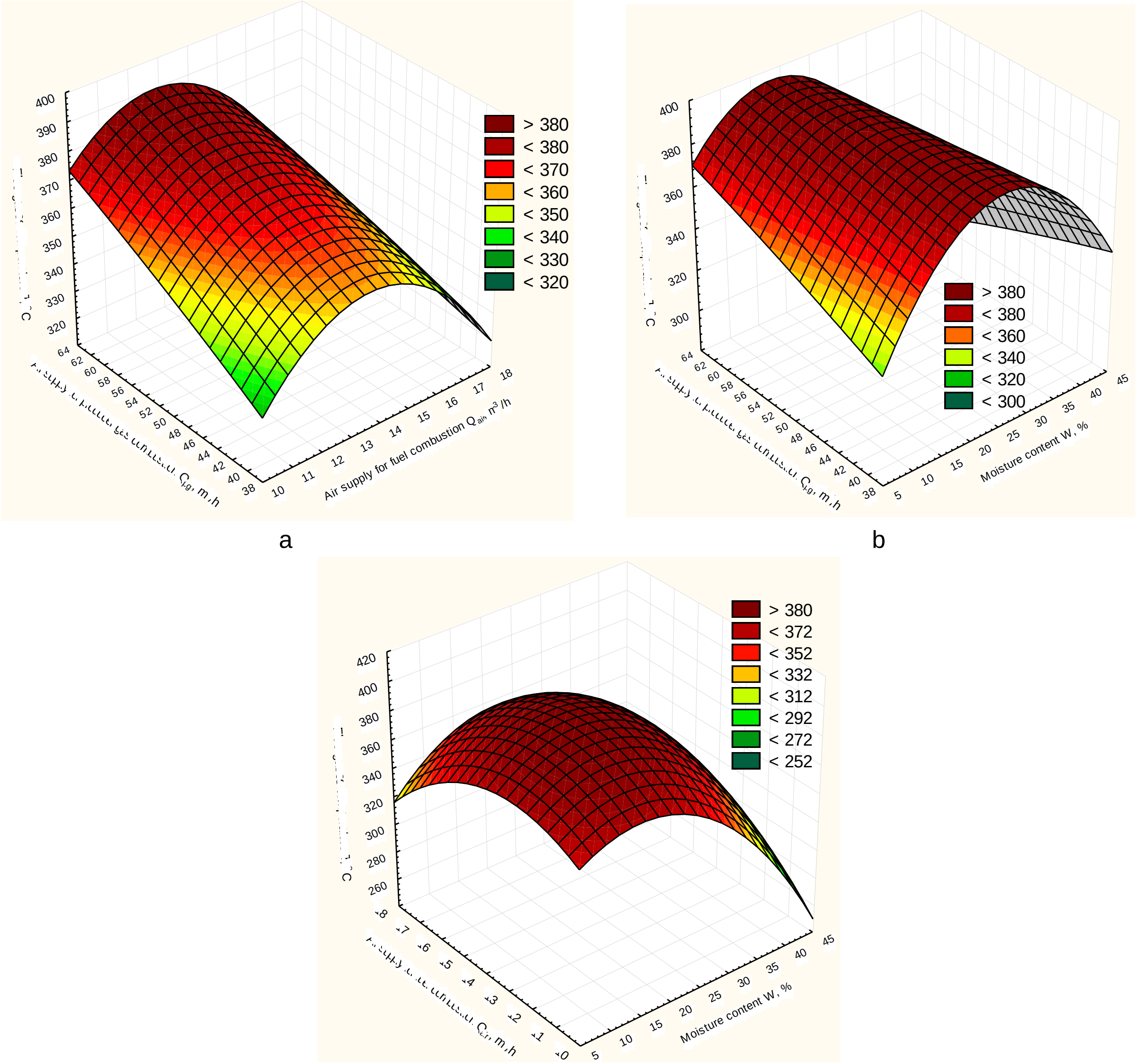
- for mixture 2:

$$T=521.61-2.76\cdot X_1+9.25\cdot X_2+1.4\cdot X_3+0.67\cdot X_1\cdot X_2-4.55\cdot X_1\cdot X_3-2.9\cdot X_2\cdot X_3-16.1\cdot X_1^2-20.42\cdot X_2^2-7.56\cdot X_3^2 \quad (12)$$

where: X_1 - encoded value of initial fuel moisture value W, %; X_2 - encoded value of the air supply for fuel combustion Q_{air}, m^3/h; X_3 - encoded value of the air supply for producer gas combustion Q_{pg}, m^3/h.

Adequacy test of hypotheses of obtained regression equation was performed by the Fisher criterion. The estimated value of this criterion in the dispersion of inadequacy $S^2_{inadeq}=27.05$ and dispersion $S_y^2=54.01$ *(mixture 1) and* $S^2_{inadeq}=3.08$, $S_y^2=6.15$ *(mixture 2)* reproducibility of the experiment was: $F^{com}=0.5$. Tabular value of Fisher's exact test adopted by the 5% of significance, according to (*Melnikov et al., 1980*), was: $F^{tabl}(0.05;\ f_1;\ f_2)=19.38$, where $f_2=8$ variance inadequacy degrees of freedom $f_1=2$ – variance experiment reproducibility degrees of freedom. Since, $F^{com}=0.5<F^{tabl}(0.05;\ f_1;\ f_2)=19.38$, the hypothesis by the adequacy of the regression equation is confirmed.

Graphical representations of the above-mentioned equation are given in fig. 2.



a b

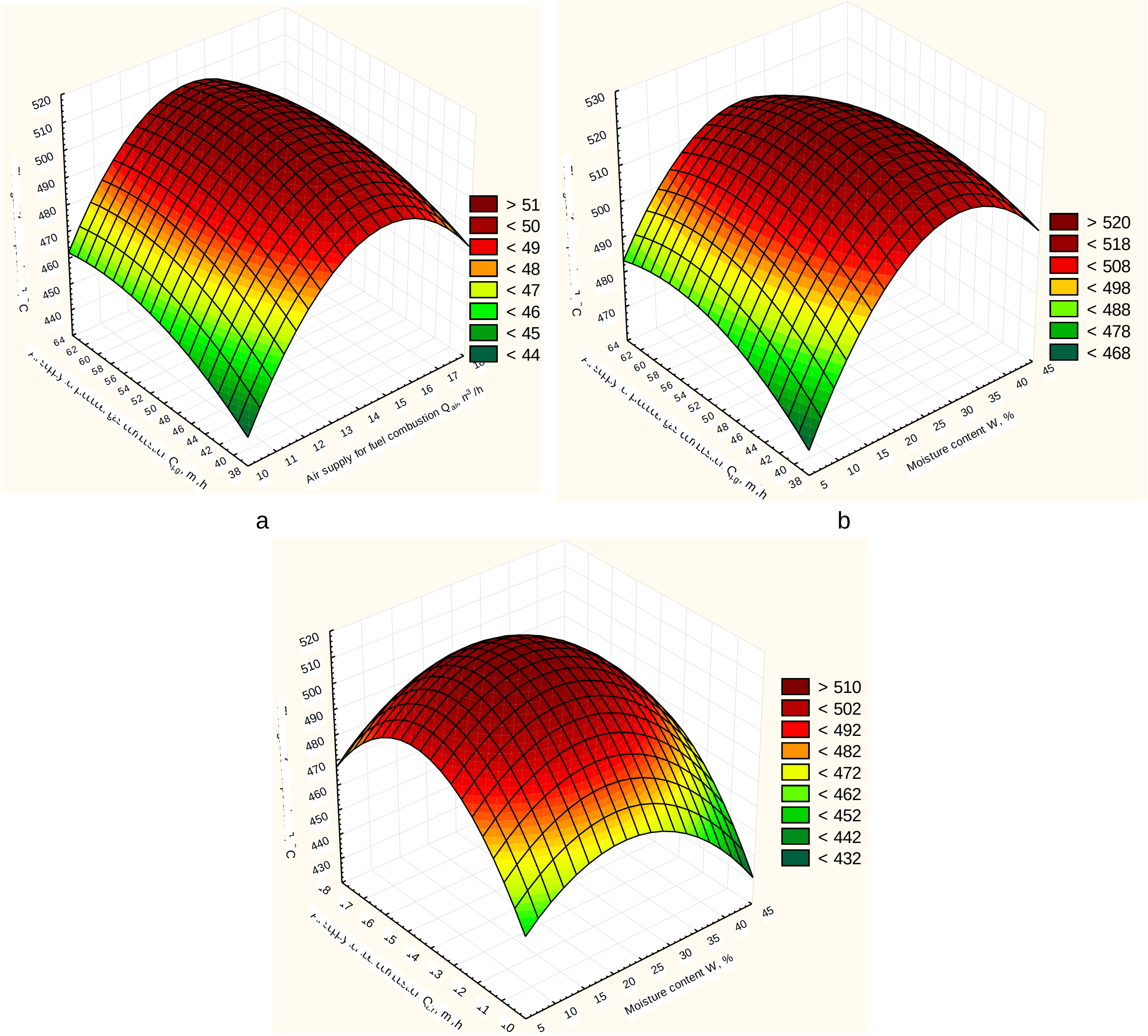
c

Fig. 2 – Response surfaces of flue gases temperature for mixture 1

a – W=10%, b – $Q_{air}=14$ *m³/h, c –* $Q_{pg}=63$ *m³/h*

Response surfaces comparison shows that flue gases temperature rises with producer gas combustion air supply and reaches maximum value when Q_{pg}=58 m³/h, fuel combustion (pyrolysis) air supply Q_{air}=14.8 m³/h and fuel moisture content W=28% (fig. 2.a, 2.b). The graphs also show the exact borders of the fuel moisture content when its burning is most effective for this particular boiler design. When moisture content is less than 20% fuel deflagrates and a very little pyrolysis gas produced that, in turn, gives lower flue gases temperature.

When moisture content grows, too much heat is expended for moisture evaporation and as a result flue gases temperature goes down. Maximum temperature in fig. 2.c is a bit lower but more clearly allocated and reached at fuel air supply Q_{air}=15.5 m³/h and moisture content 28%. Therefore, total air supply for mixture 1 is 73 m³/h, herewith it is expedient to supply 79…80% of air to gas combustion and 20…21% to fuel pyrolysis process. Such air distribution differs from what is recommended by manufacturer and is explained by fuel mixture peculiarity.



a

b

c

Fig. 3 – Response surfaces of flue gases temperature for mixture 2
a – W=10%, b – Q_{air}*=14 m³/h, c –* Q_{pg}*=63 m³/h*

For the fuel mixture 2 response surfaces gives clear maximums for flue gases temperature within optimal parameters values. If we fixate moisture content on the minimal level of 10%, the highest flue gases temperature is observed when fuel combustion air supply is 15.5 m³/h i (fig. 3.a). When fuel combustion air supply Q_{air} is fixed at 14 m³/h, maximized flue gases temperature is located within producer gas combustion air supply value 51 m³/h and fuel moisture content 27% (fig. 3.b).

For this mixture total air supply, for effective boiler functioning, is 66.5 m³/h, herewith it is expedient to supply around 76% of air for producer gas combustion process and the rest 24% for the process of fuel pyrolysis. Such distribution matches manufacturer's recommendations so this fuel mixture is well suited for the chosen boiler design.

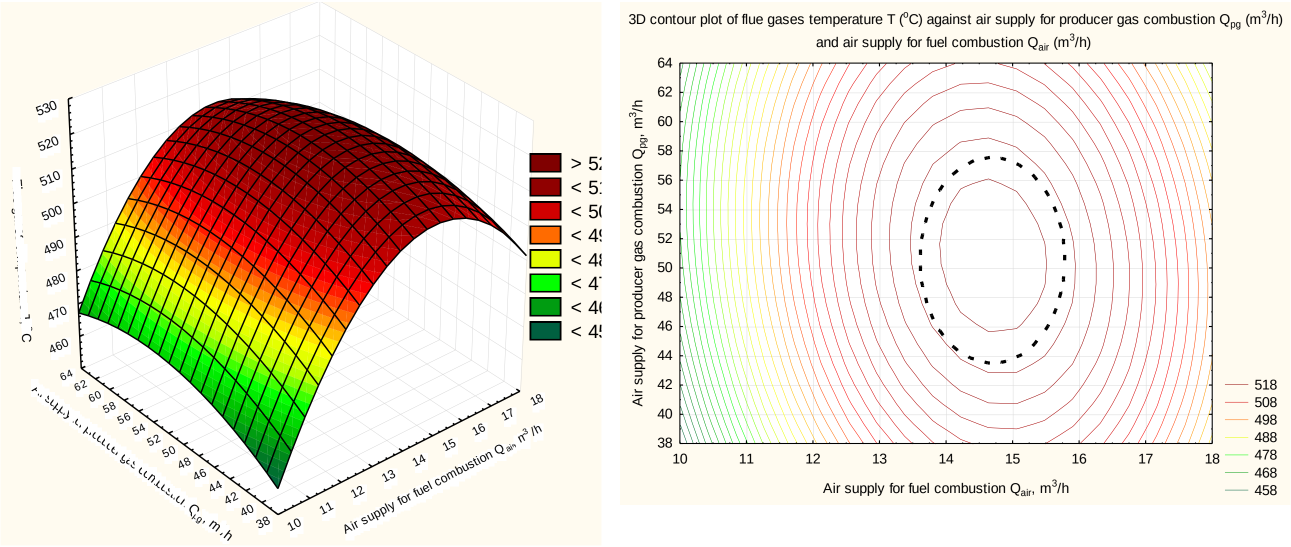
To prove the research hypothesis about defining optimal combustions modes for biomass by maximized flue gases temperature a control experiment was carried out. The point of this experiment was in defining boiler's heat productivity when changing blowing modes while burning an optimal, for this type of boiler, fuel mixture with 27% moisture content.

Based on these results there were built:

- flue gases temperature response surface for mixture 2 with moisture content W=27% (fig. 4.a) and a contour plot with the highlighted area of maximized temperature values (fig. 4.b);

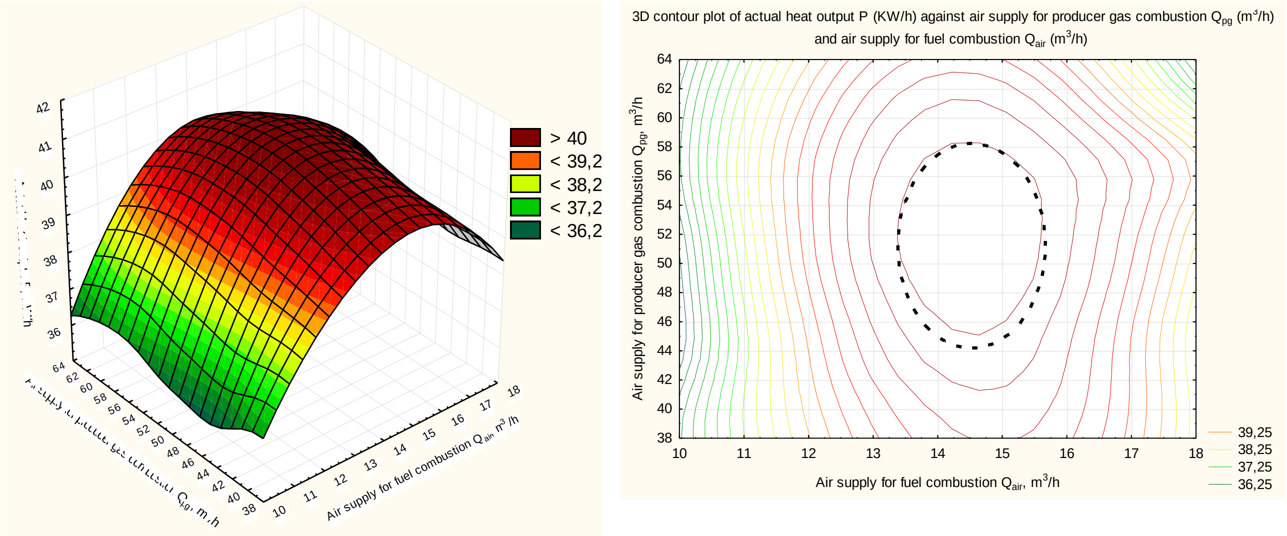
- boilers heat productivity response surface against blowing mode for the same fuel mixture 2 and *W*=27% (fig. 5.a) and contour plot with highlighted area of maximum heat productivity values (fig. 5.b).

Comparing fig. 4 and fig. 5 we can see that areas with maximum values matches. This fact proves our hypothesis.



a b

Fig. 4 – response surfaces for flue gases temperature for mixture 2 with *W=27%*



a b

Fig. 5 – Response surfaces for real boiler's heat productivity for mixture 2 with *W=27%*

CONCLUSIONS

Summing all we can say that:

1. It is defined that for any mixture of agricultural plant residues despite of its type, composition, growing, picking and storing conditions exact optimal combustion modes exists. They can be defined without elementary composition research;

2. Experimentally substantiated mode and design parameters of boiler for effective combustion of the small fracture plant wastes:

– total air supply for mixture 1 is 73 m^3/h with optimal moisture content W=28%, herewith 79…80% of air should be supplied for gas combustion and 20…21% – for the fuel pyrolysis process;

– total air supply for mixture 2 is 66.5 m^3/h with optimal moisture content W=27%, herewith 76% of air should be supplied for gas combustion and 24% – for the fuel pyrolysis process;

– chemical and mechanical combustion incompleteness for mixture 1 was 1.9% and 3.7% respectively, and for mixture 2 – 1.7% and 2.3%;

– the hypothesis that we can define upper and lower air supply by measuring flue gases temperature is confirmed by control experiment of measuring maximum heat productivity. Maximum of heat productivity was seen between the same air blowing mode values as for flue gases temperature.

Since flue gases temperature is easier to measure than heat productivity, then the described method can be recommended for defining optimal combustion parameters for complex fuel mixtures without defining its chemical composition, calorific value or any features that can influence combustion effectiveness exactly in the boilers with upper combustion. Proposed method gives us possibility to burn any fuel biomass mixtures with maximum effectiveness and heat productivity.

A perspective direction of researches is creating an automatic air blowing mode regulation system dependent on flue gases temperature, based on these results.

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