ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 58(2): 133−140, 2016
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2016.58.2.14

DETERMINATION OF EXCESS AIR RATIO DURING COMBUSTION OF WOOD CHIPS RESPECT TO MOISTURE CONTENT

Miroslav Rimár – Marcel Fedák – Aleksander Korshunov – Andrii Kulikov – Jana Mižáková

ABSTRACT

The paper deals with some problems of woodchips combustion. The method of combustion process quality evaluation is described as well as the influence of woodchips moisture content on combustion process. According to the experiments moisture content influences the excess air ratio but only minimally. As with increasing of moisture content from 10% to 60% necessary excess air ratio will increase only by10–15%.The value of excess air alpha -n represents values and reflects intrinsic ratios of excess air ratio depending on the fuel moisture. Alpha - n changes from 1.43 to 1.76 with the fuel moisture content 10–30%. This is only minimal increase and according to the measurement realizes only about 2.2% of total increase. With the subsequent increments of moisture above 30% represents an increase of excess air ratio to about 0.11–0.15 for every next 10% of the fuel humidity. Increasing of this value with increasing of values of the fuel relative humidity can explain the mechanism of moist air combustion. Alpha -d is determined by calculations on the basis of the represented mathematical model and is compared with measured values alpha-n. In this case Alpha -n reflects the fair value of excess air ratio and therefore appropriate to use it. According to the results it is necessary to have online information about the amount of oxygen, carbon dioxide and carbon monoxide in exhaust gases especially in combustion with low excess air ratio or high moisture content.

Key words: Woodchips combustion, combustion process quality, woodchips moisture, excess air ratio, combustion regulation.

INTRODUCTION

Raw materials, as a part of the logging industry can be divided into primary and secondary. Primary wood raw material used for production of round and split wood for various purposes, whips, raw materials for the chemical-technological processing and wood fuel. At some stages of the production of the wood raw material for timber a product are not used or is lost as waste due to low commodity value. This raw material may be an additional source of wood to be processed into wood chips, and other valuable products.

Solid fuels are divided into groups according to European standard Pre-Norm CEN / TS 14961. For the production of heat and electricity used wood chips, which belongs to an important group of wood biomass (this group includes firewood, pellets, briquettes).

Wood biomass is classified according to these rules of origin (a method of producing). Because of the diversity of origin of fuels in this group it varies in quality (quality indicators):

- wood chips obtained from wood-through and sanitary felling, thinning;
- wood chips obtained from wood waste, recycled waste, containing no chemical additives, and wooden structures (unsuitable for further use pallets, scaffolding and fittings, carpentry and so on. n.).

We can see a growing interest in the wood chips from landscaping on for planting in parks, recreational areas, railways, highways and rights of way, as well as wood chips produced from fast-growing trees, grown on special plantations.

The combustion of woodchips has certain specifics in comparison with fossil fuels combustion (WILLIAMS 2012, TARELHO *et al*. 2011). The combustion process can vary, but element composition of various woods is very similar (BACKREEDY *et al*. 2003, DZURENDA *et al*. 2014, NOSEK *et al*. 2016).

Moisture content of wood is the considerable factor affecting combustion process. Especially, in the case of woodchips the moisture value varies in large range, depending on the length and form of storage. In praxis, we can see woodchips combustion with moisture value of 10% as well as of 60% SKÁLA *et al.* (2007).

Additional fact affecting woodchips quality and combustion process is amount of foreign matter in fuel as bark or incombustible material (mould, stones etc.). From the above it follows that woodchips are fuel with very unstable composition in comparison with fossil fuels (coal, natural gas). The problem is to secure the combustion process of such fuel with acceptable economic and ecological conditions (combustion efficiency, pollutants production under emission limit). It requires the interconnection of combustion chamber proper construction and combustion process control JIROUŠ (1982), HOLUBČÍK *et al*. (2015), DZURENDA (2015).

The aim of combustion process control is to secure the optimum combustion (complete combustion with minimum excess of combustion air). To satisfy this condition, it is necessary to supply the combustion process with a sufficient amount of air. If insufficient amount of air is supplied, incomplete combustion occurs and the exhaust gas contains combustible components (carbon monoxide, hydrocarbons from gasification wood process). This causes not only a loss of energy but the carbon monoxide (CO) and hydrocarbons concentration are limited by the emission limit whose values are stated for individual plants. On the other hand, if too much air is supplied in comparison with optimum amount, the superfluous air absorbs the heat from the combustion and energy loss originates HAMID (2014), DZURENDA – BANSKI (2015).

Control system of combustion process has to ensure the optimum combustion during all time of plant operation. It demands the on-line evaluation of combustion process quality on the basis of exhaust gas composition analysis.

The main purpose of this work is measuring and description of the influence of moisture content of the wood chips at it combustion characteristic. For description and calculation of the influence we will use physical model of the combustion quality analyses.

EXPERIMENTAL

Procedure of combustion quality analysis and calculation

The procedure of combustion quality evaluation is based on the theory (JIROUŠ 1982). It follows from element composition of fuel and the analysis of exhaust gas. It is possible to determine the excess air ratio under the condition of incomplete combustion following stoichiometric calculations and modified relations of Ostwald diagram construction, the deal of carbon which burns out as CO and the deal of carbon which does not burn out at all. Comparing with optimum excess air ratio (complete combustion) we can determine the amount of combustion air to improve combustion process and total efficiency of the combustion machines.

The excess air ratio under a complete combustion condition is given (JIROUŠ 1982):

$$\alpha_d = \frac{0.21}{0.21-\omega_{O2}} + \frac{\omega_{O2}}{0.21-\omega_{O2}}\left(\frac{V_{SS\min}}{V_{VS\min}}-1\right) \quad [-] \tag{1}$$

where ω_{O2} is the volume fraction of oxygen in a dry exhaust gas.

The minimum amount of dry air which is necessary for a complete combustion of 1 kg of fuel is as follows:

$$V_{VS\min} = \frac{22.39}{0.21}\left(\frac{C}{12.01}+\frac{H}{4.032}+\frac{S}{32.06}-\frac{O}{32}\right) \; [\mathrm{m^3 \cdot kg^{-1}}] \tag{2}$$

where C, H, S, O, N are the mass fractions of fuel species [kg·kg^{-1}].

The minimum amount of dry exhaust gas under a complete combustion condition with stoichiometric air is as follows

$$V_{SS\min} = V_{CO2} + V_0 + \frac{21.89}{32.06}S + \frac{22.40}{28.013}N + 0.7897 V_{VS\min} \; [\mathrm{m^3 \cdot kg^{-1}}] \tag{3}$$

where the volume of CO_2 in exhaust gas from the air is given by

$$V_0 = 0{,}0003 V_{VS\min} \tag{4}$$

and the volume of CO_2, which originates under complete combustion of all carbon is as follows

$$V_{CO2} = \frac{22.27}{12.01}C \tag{5}$$

The volume of oxygen needed to combustion of all carbon is given by

$$V_{O2}(C) = \frac{22.39}{12.01}C \tag{6}$$

The excess air ratio α_n under an incomplete combustion condition with known volume fractions of oxygen ω_{O2}, carbon dioxide ω_{CO2} and carbon monoxide ω_{CO} in dry exhaust gas is given JIROUŠ (1982):

$$\alpha_n = \frac{k_1\omega_{O2} + k_2\omega_{CO2} + k_3\omega_{CO} + k_4}{p_1\omega_{O2} + p_2\omega_{CO2} + p_3\omega_{CO} + p_4} \; [-] \tag{7}$$

with coefficients

$$p_1 = V_{CO}(V_0V_3 + V_{CO2}V_{VS\min}) \tag{8}$$

$$p_2 = V_{CO}V_{VS\min}\left(V_{O2}(C) - 0.21V_3\right) \tag{9}$$

$$p_3 = 0.21V_{CO2}V_{VS\min}\left(V_2 - V_3\right) + 0.5V_{O2}(C)(V_{CO2}V_{VS\min} + 2V_0V_2 - V_0V_3) \tag{10}$$

$$p_4 = -V_{CO}(V_0V_{O2}(C) + 0.21V_{CO2}V_{VS\min}) \tag{11}$$

$$k_1 = -V_{CO}(V_1 + V_3)V_{CO2} \tag{12}$$

$$k_2 = -V_{CO}\left(V_1 V_{O2}(C) + 0.21 V_3 V_{VS\min}\right) \tag{13}$$

$$k_3 = V_{CO2}\left(0.5 V_{O2}(C)(V_3 - V_1 - 2V_2) + 0.21 V_{VS\min}(V_2 - V_3)\right) \tag{14}$$

$$k_4 = V_{CO} V_{CO2}\left(V_{O2}(C) - 0.21 V_{VS\min}\right) \tag{15}$$

$$V_1 = V_{SS\min} - V_{VS\min} \tag{16}$$

$$V_2 = V_{CO} + 0.5 V_{O2}(C) - V_{CO2} \tag{17}$$

$$V_3 = V_{O2}(C) - V_{CO2} \tag{18}$$

$$V_{CO} = \frac{22.37}{12.01} C \tag{19}$$

The necessary amount of combustion air V_{Vd} under a complete combustion condition for given amount of fuel q_p could be determined by:

$$V_{Vd} = \alpha_d V_{VS\min} q_p \qquad [\mathrm{m^3 \cdot h^{-1}}] \tag{20}$$

The amount of fuel supply can be estimated from power consumption of plant P:

$$q_p = \frac{P}{\eta Q_v} \qquad [\mathrm{kg \cdot h^{-1}}] \tag{21}$$

where η is the efficiency of combustion process,

Q_v is the calorific value of fuel.

Similarly, it is possible to determine the amount of combustion air V_{Vn} supplied to combustion chamber under an incomplete combustion condition:

$$V_{Vn} = \alpha_n V_{VS\min} q_p \qquad [\mathrm{m^3 \cdot h^{-1}}] \tag{22}$$

Thus the difference between the amount of the combustion air ΔV_V with both a complete combustion and incomplete combustion is given by

$$\Delta V_V = (\alpha_d - \alpha_n) V_{VS\min} q_p \qquad [\mathrm{m^3 \cdot h^{-1}}] \tag{23}$$

Given calculation method was applied to find and analyze some characteristic of the combustion machines.

RESULTS AND DISCUSSION

Woodchips moisture and its influence on combustion process quality

According to the part introduction it follows that the moisture content of woodchips considerably influences the combustion behavior. Than we tried to evaluate this influence on combustion process quality represented by the value of excess air ratio. For this purpose we will also use the above described procedure.

We assume the woodchips with an average composition with moisture content W from 10% to 60%. To consider the fuel composition, we can estimate the values of excess air ratio under a complete combustion condition.

Tab. 1 Input values for calculation.

C	H	N	O	A	W	ω_{O2}	ω_{CO2}	ω_{CO}
0,441	0,055	0,002	0,39	0,012	0,1	0,11	0,095	0,0007
0,392	0,049	0,002	0,347	0,01	0,2	0,11	0,095	0,0007
0,343	0,043	0,001	0,304	0,09	0,3	0,11	0,095	0,0007
0,294	0,037	0,001	0,26	0,08	0,4	0,11	0,095	0,0007
0,245	0,031	0,001	0,216	0,07	0,5	0,11	0,095	0,0007
0,215	0,027	0,001	0,185	0,06	0,6	0,11	0,0950	0,0007

Next we assume an incomplete combustion with amount of carbon monoxide ω_{CO} in exhaust gases reaching emission limit. The values of oxygen ω_{O2} and carbon dioxide ω_{CO2} will be standard in the case of woodchips combustions (BACKREEDY *et al.* 2004). The input values of the both calculations of excess air ratio are shown in Tab. 1.

We can estimate the excess air ratio under both of complete combustion and incomplete combustion condition in dependence on woodchips moisture content on the basis of relations listed in previous part. The dependence is shown in Fig. 1, where alfa – d (α_d) is complete combustion, alfa – n (α_n) is incomplete combustion.

Excess air α_d in Fig. 1 characterizes by the equation (1) and determines by calculation on the basis of the represented mathematical model. α_d indicates the amount of necessary air for complete combustion, in which exhaust gases does not contain combustible components. Relationship of the V SS min to V VS min ratios in equation (1) minimizes the effect of relative humidity of fuel and exhibits the linear course. Values of excess air ratio α_n are measured values. α_n expresses actual ratios of excess air ratio depending on the fuel moisture. Increase of this value with increasing of relative humidity values can be explained by the mechanism of combustion of moist air. α_n express the real value of excess air ratio and is appropriate to use it.

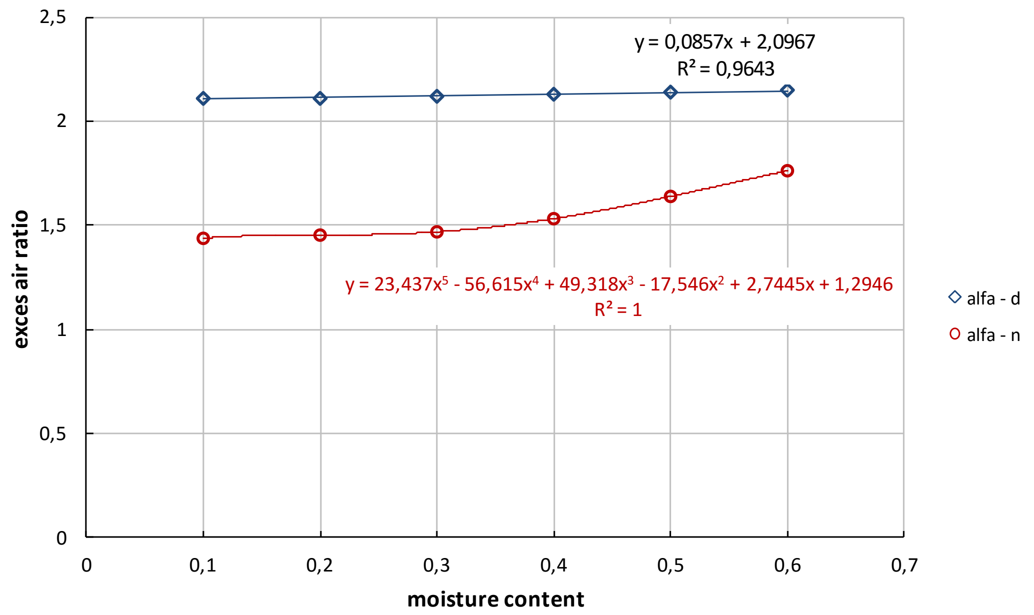

Fig. 1 The dependence of excess air ratio on the moisture content.

The value of excess air ratio under a complete combustion condition is almost constant for all values of moisture content (the different is negligible and less than 5%). On the other hand, the value of excess air ratio under incomplete combustion condition slightly increases with growth of moisture content (the change is approximately up to 15%) with the major increase (apprx.12−15%) between moisture content 30−50% while increase between moisture content 10−30% is under 5%. This dependence is deduced under condition of constant values of oxygen and carbon dioxide in exhaust gases for all values of moisture content. Of course, in praxis, these values are changed. So, moisture content influences the excess air ratio but only minimally.

However, we must consider other aspects of moisture content influence on combustion process. The main influence of moisture content on combustion process falls in reducing of combustion temperature, whereas the portion of energy from combustion is consumed to evaporate the moisture and to heat the water vapor. This fact slows down the combustion process, efficiency of the combustion machine and an incomplete combustion occurs. To keep the production of pollutants (especially CO) in emission limit range it is necessary to measure and know total moisture content of the current woodchips and on-line control of their CO amount in exhaust gas and if necessary to adjust the combustion air supply (RAVEENDRAN *et al.* 1996).

CONCLUSION

According to the calculations and results described procedure enables to determine the quality of combustion process by means of exact calculation of excess air ratio under both complete and incomplete combustion conditions with the different moisture content of the wood chips. In order to apply this method to combustion process control, it is necessary to have on-line information about the amount of oxygen, carbon dioxide and carbon monoxide in exhaust gases. Modern analyzers make possible independent measuring of these components with very high accuracy and speed (SKÁLA *et al*. 2007). Owing to such control systems of plant, managers can immediately evaluate the combustion process quality and consequently adjust the combustion in order to approach the optimum one (by means of primary and secondary air supply control, fuel supply, etc.).

It has to be mentioned that some devices for woodchips combustion are constructed with on-line measuring of oxygen in exhaust gas (lambda probe). Following above mentioned theory the measurement of amount of oxygen only in exhaust gas is deficient to evaluate combustion process quality and cannot be used to exact control of combustion process according to the modern norms and rules of EU.

REFERENCES

BACKREEDY, R., JONES, J., POURKASHANIAN, M., Williams, A. 2003. Burn-out of coal and biomass chars Fuel, 82, p. 2097–2105.

DZURENDA, L. 2015. Model of heat load on the atmosphere by flue gases. Manufacturing Technology 15(5): 804–808. ISSN 1213-2489.

DZURENDA, L., BANSKI, A. 2015. Dependence of the boiler flue gas losses on humidity of woody biomass. Archives of Thermodynamics 36(4): 77–86. ISSN 2083-6023.

DZURENDA, L., BANSKI, A., DZURENDA, M. 2014. Energetic properties of grenn wood chips from *Salix viminalis* grown on plantations. Scientia agriculturae bohemica, 45(1): 44–49.

GLASSMAN, I., YETTER, R. 2008. Environmental combustion considerations. In Combustion (4th ed.), Academic Press, Burlington, p. 409–494.

HAMID S. 2014. An experimental study of combustion and emissions of two types of woody biomass in a 12-MW reciprocating-grate boiler. 135: 120–129.

HOLUBČÍK, M., JANDAČKA, J., PAPUČÍK, S., PILÁT, P. 2015. Performance and emission parameters change of small heat source depending on the moisture. Manufacturing Technology, 15(5): 826–829.

JIROUŠ, F. 1982. Početně analytická kontrola spalování. Strojírenství 32(4): 199–203.

MOGHTADERI, B., MEESRI, R., WALL, T. F. 2004. Pyrolytic characteristics of blended coal and

woody biomass. Fuel, p. 745–750.
NOSEK, R., HOLUBCIK, M., JANDACKA, J. 2016. The impact of bark content of wood biomass on biofuel properties. BioResources, 11(1): 44–53.
RAVEENDRAN, K., GANESH, A., KHILAR, 1996. Pyrolysis characteristics of biomass and biomass components. Fuel, 75(8): 987–998.
SKÁLA, Z. OCHODEK, T.2007. Energetické parametry biomasy. Projekt GAČR 101/04/1278. 1. vid., Brno : Mantila repro 2007. ISBN 978-80-214-3493-6
TARELHO, L., NEVES, D., MATOS, M.,A. 2011. Forest biomass waste combustion in a pilot-scale bubbling fluidised bed combustor. In Biomass Bioenergy, p. 1511–1523.
WILLIAMS, A. 2012. Pollutants from the combustion of solid biomass fuels. Progress in Energy and Combustion Science. 38(2): 113–137.
ZHANG, X., CHEN, Q., BRADFORD, R., SHARIFI, V., SWITHENBANK, J. 2010. Experimental investigation and mathematical modelling of wood combustion in a moving grate boiler. In Fuel Process Technol, p. 1491–1499.

Acknowledgements

This paper is supported by the VEGA 1/0338/15 „Research of effective combinations of energy sources on the basis of renewable energies“.

Authors' addresses

prof. Ing. Miroslav Rimár, CSc.
Ing. Marcel Fedák, PhD.
Technical University of Košice
Faculty of Manufacturing Technologies
Technical University of Košice with a seat in Prešov
Department of Process Technique
Štúrova 31
080 01 Prešov
Slovakia
miroslav.rimar@tuke.sk
marcel.fedak@tuke.sk

Prof. Dr. Korshunov Aleksander, Dr.Sc.
Votkinsk Branch of Kalashnikov Izhevsk State Technical University
Department of "Higher Mathematics, Physics, Chemistry"
Studencheskaya 7
Izhevsk, 426069
Russia
kai@istu.ru

Ing. Andrii Kulikov
Technical University of Košice
Faculty of Manufacturing Technologies
Technical University of Košice with a seat in Presov
Department of Process Technique
Sturova 31
080 01 Presov
Slovakia
andrii.kulikov@tuke.sk

PaedDr. Jana Mižáková, PhD.
Technical University of Košice
Faculty of Manufacturing Technologies
Technical University of Košice with a seat in Presov
Department of Mathematics, Informatics and Cybernetics
Bayerova 1,
080 01 Presov
Slovakia
jana.mizakova@tuke.sk