

Original Research

EFFECT OF AIR OXYGEN ENRICHMENT AND EXCESS AIR RATIO ON SOLID FUELS COMBUSTION

DOI: 10.5937/EcoTER26040R

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Abstract

The subject of this article is an analysis of the influence of air oxygen enrichment and excess air on the solid fuel combustion and the GHG emission. Combustion conditions for three different chemical compositions and heating values of solid fuels are defined by changes in values of O_2 (21–30%) and λ (1.2–1.4). GHG emission is defined as the sum of CO_2 and NO_x . For all analyzed solid fuels, the correlation of $\%O_2$, excess air ratio, flame temperature, volume of combustion products and GHG emissions was calculated. The results were obtained using analytical method. The flame temperature increase with increasing values of $\%O_2$ and as a results of this, emission of NO_x increases. This can be explained by statement that at higher combustion temperature, volume of thermal NO_x increase. On the other hand the combustion temperature decreases for all fuel types.

Keywords: flame temperature, combustion, excess air ratio, NO_x .

INTRODUCTION

Improvements in the overall energy efficiency of an industrial plant are primarily achieved by reducing the energy input values and also the energy losses on the output side of a process step [1]. The changes in combustion conditions, especially fuel of lower heating value, causes a change in combustion temperature and volume of gaseous products. The changes in air excess in furnaces mainly affect the extent of NO_x (formed from nitrogen contained in the volatile matter) emission[2,3].

Air excess ratio determines some combustion characteristics and affects NO_x emissions [4,5]. Oxygen-enriched combustion technology is accomplished by raising the oxygen content in the intake air, enabling combustion to be mainly governed by the mass ratio of oxygen to fuel instead of the conventional air-fuel ratio [6]. The fuel-combustion process is significantly affected by the heating value of fuel, the amount of combustion air, the air-preheating temperature, the oxygen enrichment in the air and waste gas temperature.

One of the key objectives of thermal engineering calculations for fossil fuel combustion is to define the conditions and determine the quantities that influence heat exchange

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intensification, reduce specific fuel consumption, and minimize the harmful impact of exhaust gases on the environment.

MATERIALS AND METHODS

The central hypothesis of this paper is that an analytical correlation exists between the chemical composition of the fuel mixture, the air enrichment, excess air ratio and the emission of primary combustion byproducts (CO_2 , NO_x), which have a dominant impact on air pollution.

One of the key objectives of thermal engineering calculations for fossil fuel combustion is to define the conditions and determine the quantities that influence heat exchange intensification, reduce specific fuel consumption, and minimize the harmful impact of exhaust gases on the environment.

For these calculation the varying composition of solid fuels (S1,S2,S3) are used as shown in the Table 1.

Table 1 The chemical composition of solid fuels (%)

	C	H	O	N	S	W	A
S1	70	5.5	4.2	1.5	4.8	3.0	11.0
S2	75	4.2	3.0	2.1	4.2	2.5	9.0
S3	79	2.5	2.5	2.5	3.0	2.5	8.0

The values of the oxygen content in combustion air for each analyzed fuel were selected from a range $21 \div 30\%$, and values of excess air ratio: $\lambda = 1.2 \div 1.4$, (Table 2). The heating values (Q_d) are calculated on the base of fuel chemical composition.

Table 2 The content of the oxygen in combustion air, Q_d , and λ for analyzed fuels

	S1	S2	S3
λ	$1.2 \div 1.4$	$1.2 \div 1.4$	$1.2 \div 1.4$
Q_d (MJ/kg)	29.41	29.91	29.12
% O_2	$21 \div 30$	$21 \div 30$	$21 \div 30$

Combustion products (V_c) primarily determined by combustion temperature (t_c) significantly impacts greenhouse gas emissions, its dependence on the excess air coefficient (λ) was determined analytically.

RESULTS AND DISCUSSION

Analysis of the calculation results reveals two opposing trends in the influence of an increasing coefficient λ . As the value of λ increases, the volume of combustion products rises linearly, while the combustion temperature decreases for all fuel types (Figure 1).

The difference is reflected in the absolute values of these quantities, which result from the different chemical composition as well as the value of the excess air coefficient (λ) itself.

When these dependencies are viewed from the perspective of thermal efficiency in the combustion process, it is evident that any reduction in combustion temperature decreases the thermal effect, which is undesirable.

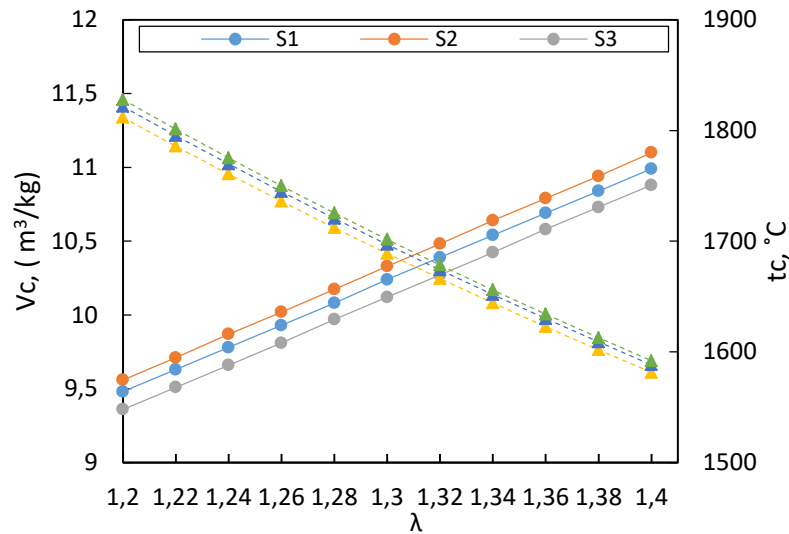


Figure 1 Combustion temperature of solid fuels and products volume as a functions of λ

On the other hand, if the primary focus is environmental protection, any increase in V_c generally leads to higher emissions of gaseous pollutants, unless it is predominantly influenced by combustion temperature. Both of these seemingly negative effects are, in fact, a “compromise” with the necessary process parameters, which require a certain excess of air.

The Figure 2 illustrates the dependence of CO_2 emissions per unit mass of solid fuels, as well as the relative % of CO_2 in the total volume of gaseous products. Excess air, which is a technological prerequisite for stable combustion, does not participate in the reaction itself and, therefore, does not contribute to an increase in CO_2 emissions.

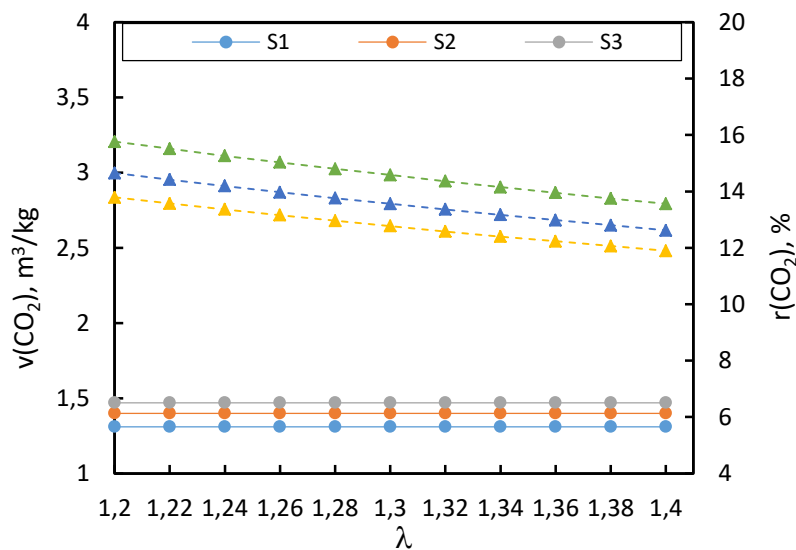


Figure 2 Volume of CO_2 as a functions of λ

Based on the discussed mechanisms of NO_x formation during the combustion of different fuel types, the influence of the excess air coefficient (λ) on NO_x emissions and their volume share in the total combustion products is defined (Figure 3).

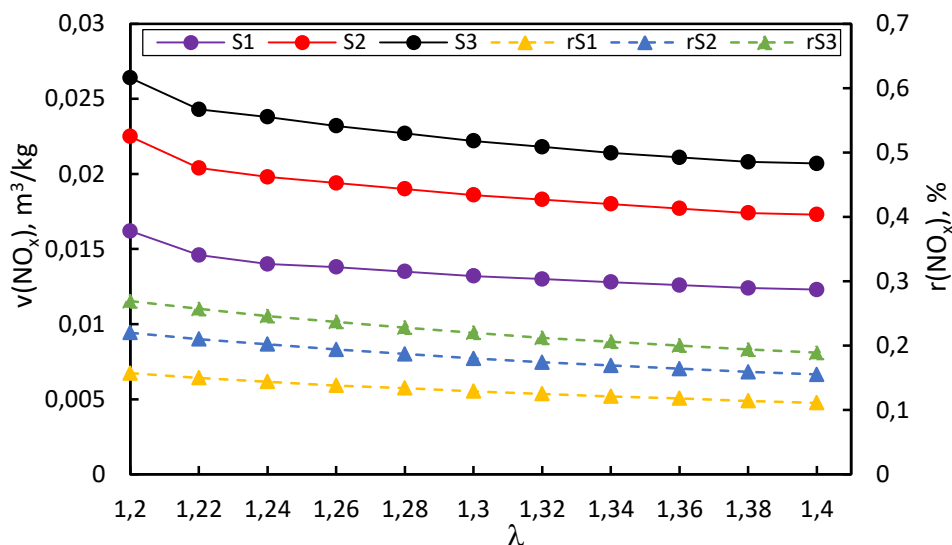


Figure 3 Volume of NO_x as a functions of λ

As the excess air coefficient (λ) increases, the specific NO_x volume per unit of fuel decreases following a slightly exponential relationship. Because to compare different fuels in terms of greenhouse gas emissions, emission coefficient $K(\text{NO}_x)$ is often used the influence of excess air on this coefficient is defined (Figure 4).

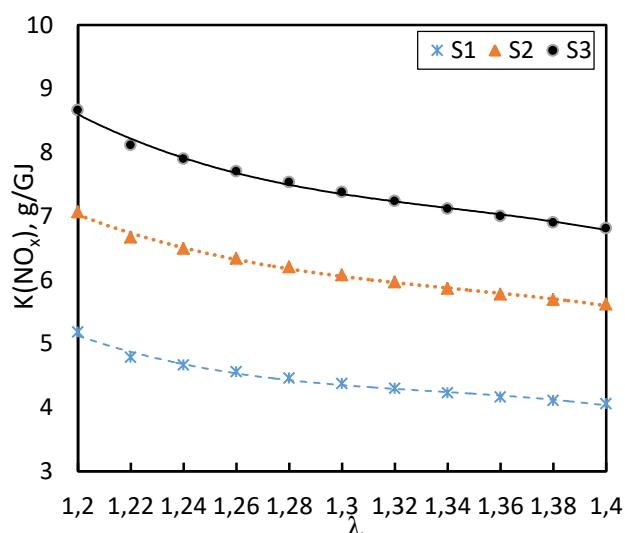


Figure 4 The coefficient of NO_x emission as a functions of λ

In all analysed cases, for all solid fuel types, the NO_x emission coefficient decreases as λ increases, following a slightly exponential trend, which is a consequence of the reduction in combustion temperature.

As a consequence of the intensification of the combustion process, there is a change in the flame temperature and the volume of the combustion products formed. As typical, representative examples of the interdependence of the mentioned parameters, graphs related to the average value of the coefficient $\lambda=1,3$ from the analyzed range for all solid fuel, are presented (Figure 5).

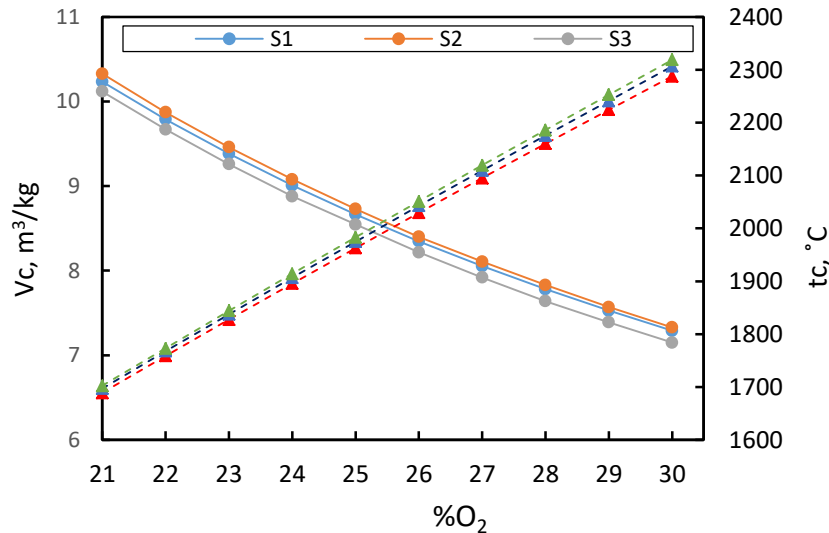


Figure 5 The influence of oxygen enrichment on the temperature and combustion products volume

Graphical presentations of the derived calculations show that with the enrichment of air for combustion, i.e., with the increase in the percentage of oxygen in it, the volume of combustion products decreases, and the flame temperature increases.

The influence of the O₂ content in enriched air on the volumetric emission of NO_x and the emission coefficient K(NO_x) is shown in the Figure 6.

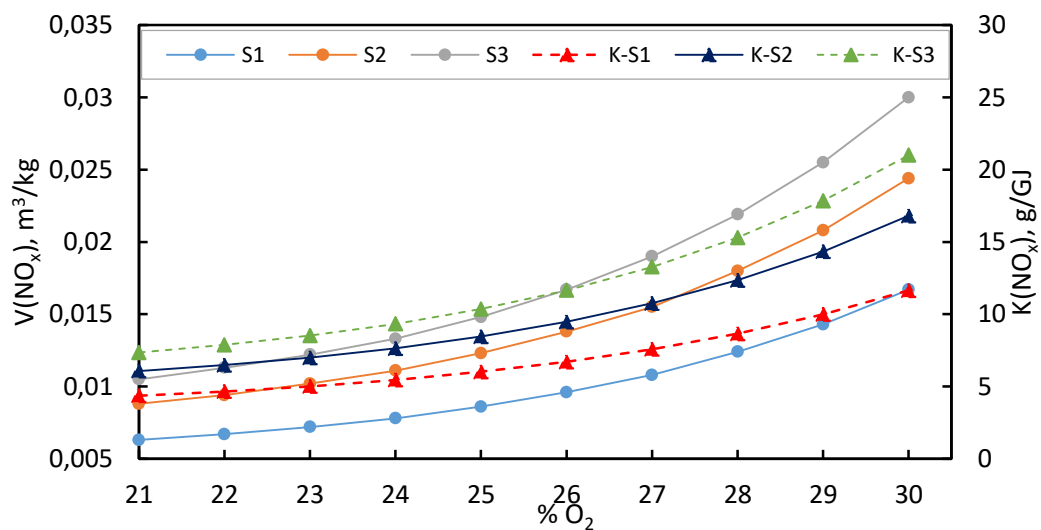


Figure 6 The influence of % O₂ on the volume and the emission coefficient K(NO_x)

Analytical calculations were performed for all types of fuel and all values of the excess air coefficient, but only the graphical dependencies for the average value of $\lambda=1,30$ are shown. For all analyzed solid fuels, it is observed that NO_x emissions increase with air enrichment, i.e., with the increase in % O_2 , more or less according to an approximately exponential law.

CONCLUSION

An increase in the value of λ leads to a linear rise in the volume of combustion products and a decrease in combustion temperature for all analysed solid fuels. The excess air coefficient does not influence CO_2 emissions, which primarily depend on the chemical composition of the fuel but it does reduce CO_2 's relative share in the combustion products due to the increased total volume.

Increase in λ generally results in a reduction in the unit volume emission $V(\text{NO}_x)$ and the emission coefficient $K(\text{NO}_x)$. For all analyzed fuels, with the increase in % O_2 , the volume of combustion products decreases, and the flame temperature increases. Considering this, the most favorable heat technology indicators are achieved at an enrichment of 30% O_2 , but the environmental effects must also be taken into account.

With the increase in O_2 content, the combustion temperature significantly increases, which is the basic precondition for the formation of “thermal” NO_x , so that enriching the air with oxygen leads to an increase in NO_x emissions.

REFERENCES

- [1] Lalović, M., Radović, Ž., Jauković, N. *Materiali in Tehnologie* 2006, 40 (3), 89–92.
- [2] Gil, S., *Fossil Fuel and the Environment*, Dr. Shahriar Khan (Ed.), 2012, p. 37–61.
- [3] Song, W., Defu, C., Zhiguo, W., *et al.* *Energies* 2020, 13(14), 3557.
- [4] Ding, H. Ziqu, O., Xiaoyang, C., *et al.* *Journal of Thermal Science* 2023, 32, 1263–1277.
- [5] Abbassi, M., Domenico, L. Cornelis, V. *Processes* 2021, 9, 1723.
- [6] Wang, H.Y. *Processes* 2024, 12, 2282–2288.