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THE EFFECT OF OXYGEN ENRICHMENT OF COMBUSTION AIR ON THE AMOUNT AND CHEMICAL COMPOSITION OF COMBUSTION PRODUCTS*

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The results of the calculation of liquid fuel combustion are presented in this paper. The subject of the work is the analysis of the effect of combustion air enriching on the amount and chemical composition of combustion products. Conditions of the combustion process were defined by changes in values of the excess air ratio (λ=1.0-1.20), oxygen content in the combustion air ($v(O_2)$ = 21-30 %), hot gas outlet temperature (600-1100 ^{o}C), while the value of the air preheated temperature (t_v=400 ^{o}C), as well as a chemical composition of the fuel, were constant. The total losses of heat in waste flue gases can be minimized by providing a proper amount of the combustion air. The amount of waste gases can be minimized and the heating rate of the unit can be increased by the oxygen enrichment of the combustion air. Also, using the enriched air, the concentration of nitrogen and NO_x emission in the furnace atmosphere can be reduced by reducing the amount (volume) of the combustion air needed.

Key words: combustion, air enrichment, combustion products, NO_x emission

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INTRODUCTION

One of the main priorities needed for metal industry is improving furnace efficiency, *i.e.* finding a way to reduce the energy usage and emissions of CO_2 an NO_x while increasing furnace efficiencies and improving productivity.
Such efficiency improvements can be achieved by better insulation and by reducing stack losses. The appropriate technology and thermal process in metal industry can reduce the energy usage and gases emissions, improve the productivity and reduce the capital and operational costs [1, 2].
The air used in most part of the industrial combustion processes as an oxidizing agent, has high nitrogen content (78-79 %). In the process of combustion fuel, nitrogen is useless thermal ballast. During the air-fuel combustion, the chemically inert nitrogen in the air dilutes the reactive oxygen and carries away some of the energy in the hot combustion exhaust gas. An increase in oxygen in the combustion air can reduce the energy loss in the exhaust gases and increase the heating system efficiency.
The performance of many air-fuel combustion processes can be improved by enriching the combustion air with oxygen. In order to reduce the overall fuel and energy consumption, or to substitute a very expensive fuel with a poor one in many industrial heating processes, oxygen enrichment of the combustion air may be very effective.
Oxygen enrichment can increase the overall system efficiency. The flue gas heat losses are reduced because the flue gas mass decreases as it leaves the furnace, so there is less nitrogen to carry heat from the furnace. Certain burners and oxy-fuel fired systems can achieve lower levels of NO_x, CO and hydrocarbons. The increase of the oxygen content allows more stable combustion and higher combustion temperatures that can lead to a better heat transfer. When a furnace has been converted to be oxygen enriched, throughput can be increased for the same fuel input because of the higher flame temperature, the increased heat transfer to the load, and a reduced flue gas [3-5].
Air enrichment can increase both the flame temperature and the thermal efficiency of the furnace. The final results of the oxy-fuel combustion is a substantial improvement of the temperature stability, a better heat transfer, the productivity increase, while, at the same time, a reduced amount of the combustion air and waste flue gases, with low NO_x emissions. Using oxygen enrichment of the combustion air for specific applications may improve the efficiency, depending on the exhaust gas temperature and the percentage of oxygen in the combustion air [5, 6-9].

RESULTS AND DISCUSSION

The results given in this paper were obtained by combining an experimental technique with an analytical method of combustion calculation of a chosen type of liquid oil. They are related to the work of a special type of a continuous furnace for the steel billet heating prior to hot rolling. The combustion air was preheated and enriched (temperature above 20 ^oC and oxygen content was more than 21 vol%),
The working conditions of fuel combustion process were defined by:

- changes in excess air values, λ = 1.00 – 1.20;

- inlet temperature of cold combustion air, t_{ai} = 20 ^oC;
- temperature of preheated air, t_{ap} = 300 ^oC;
- oxygen content in combustion air, $v(O_2)$ = 21 – 30 %;
- inlet temperature of the combustion products, t_{gi} = 800 ^oC;
- outlet temperature of the combustion products, t_{go} = 300 ^oC;

The values of λ, $v(O_2)$, t_{ap}, t_{gi}, t_{go} were chosen according to the required thermal conditions and temperature profile in the furnace for low alloy steel billets heating. Some results of the combustion calculation of heavy oil in industrial conditions of a reheating furnace operation are presented in this paper.

The chemical composition and heating value of the fuel are given in Table 1.

Table 1. Chemical composition and heating value of fuel

Elements content (mas %): 84,719 % C; 12,375 % H; 1,541 % S; 0,517 % O; 0,219 % N; 0,029 % A; 0,60 % W; (A – ash; W – water)
Heating value: Q = 41560,916 kJ/kg

Calculations of the fuel combustion (heavy oil combustion) process are necessary to determine the air requirements, the amount and combustion products composition, *i.e.* the content of oxygen, nitrogen and carbon dioxide.

The results of the mathematical calculation of combustion process are available in the form of graphs, as well as in the form of the table.

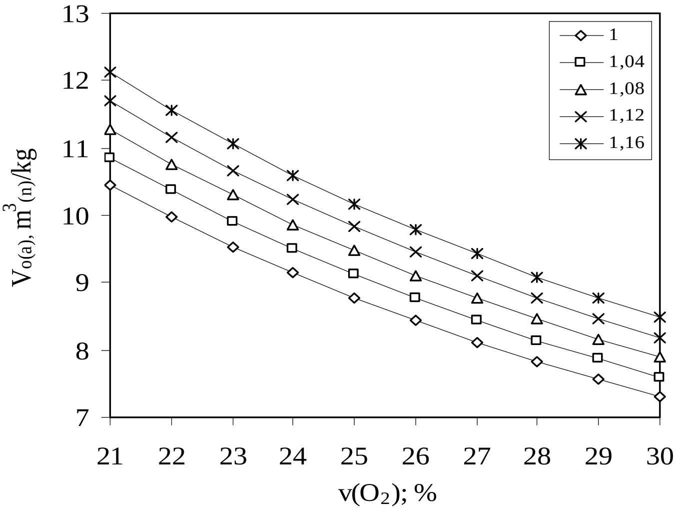

Figure 1.The effect of oxygen content in the combustion air on the amount of air (λ = 1.00; 1.04; 1.08; 1.12; 1.16)

The amount of the combustion air and the amount of combustion products can be defined as the functions of the oxygen content in the combustion air and the excess air ratio values. The changes of the amount of the combustion air (V_{ca}) and combustion products, *i.e.* the waste gas amount values (V_{cp}), including the influence of the air's oxygen content and the excess air ratio values, were presented in Figures 1 and 2. These changes significantly affect the main heating parameters. The curves describe dependence of variation in oxygen content values on the changes of the amount of combustion air (Fig. 1) and on the amount of combustion products (Fig. 2). These graphs are extended to include the influence of the excess air ratio values (λ = 1.00; 1.04; 1.08; 1.12; 1.16).

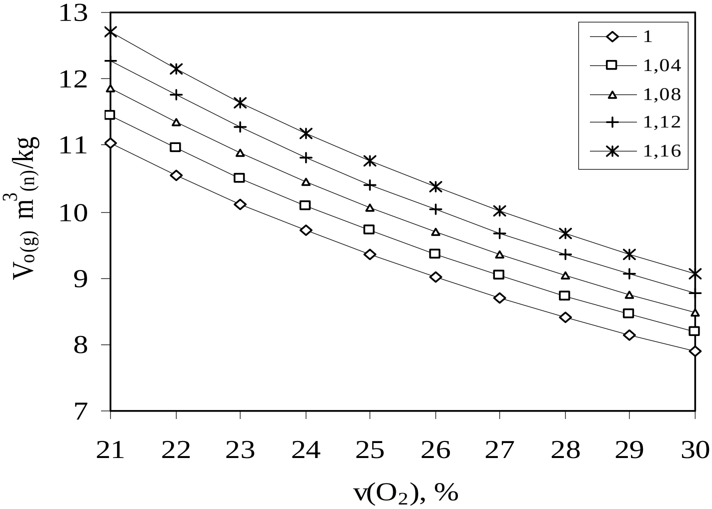

Figure 2.The effect of the oxygen content in the combustion air on the amount of combustion products (λ = 1.00; 1.04; 1.08; 1.12; 1.16)

By increasing the content of oxygen in the air, the amount of air per unit of fuel is decreased (Fig. 1), as a result of which the amount of produced flue gases (waste gases) also decreases (Fig. 2). According to the data shown in Fig. 1 and Fig. 2, it can be concluded that the values of the air amount and combustion products also increase with the increase of the excess air ratio for the total range of the oxygen content in the combustion air.

The results of the calculation of the combustion products composition were presented in Figures 3-5, for the air preheating temperature in the interval 21 – 30 % O_2 in the combustion air and for three values of the excess air ratio (λ = 1.04; 1.12; 1.20). Preheating temperature of the combustion air was constant (300 ^oC).

The changes of chemical composition of combustion products can be analyzed by the changes of O_2 (Fig. 3), CO_2 (Fig. 4) and N_2 (Fig. 5) values. According to the given results it can be seen that with the air enrichment, the content of O_2 and CO_2 in combustion products increases, while the content of N_2 decreases.

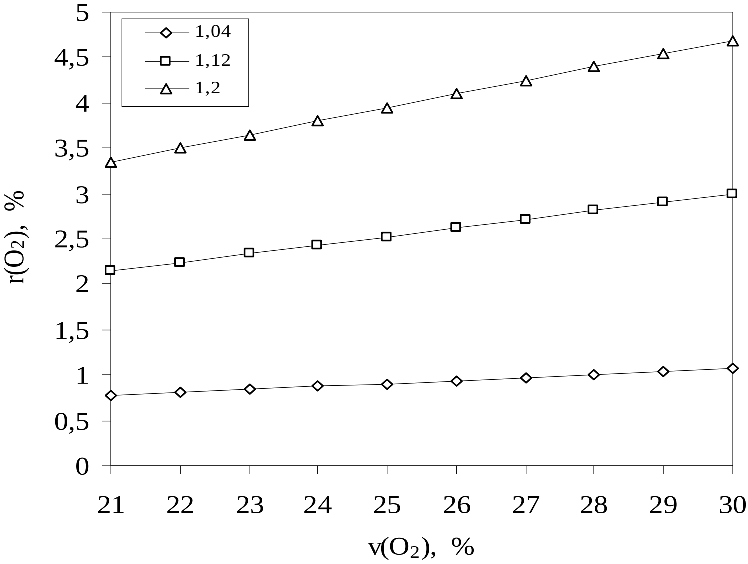

Figure 3.The content of O_2 in combustion products as a function of air enrichment (λ = 1.00; 1.04; 1.08; 1.12; 1.16).

By increasing the oxygen content in the combustion air, a total amount of supplied air and combustion products decrease, which can result in a decrease of N_2 content in the products of combustion.

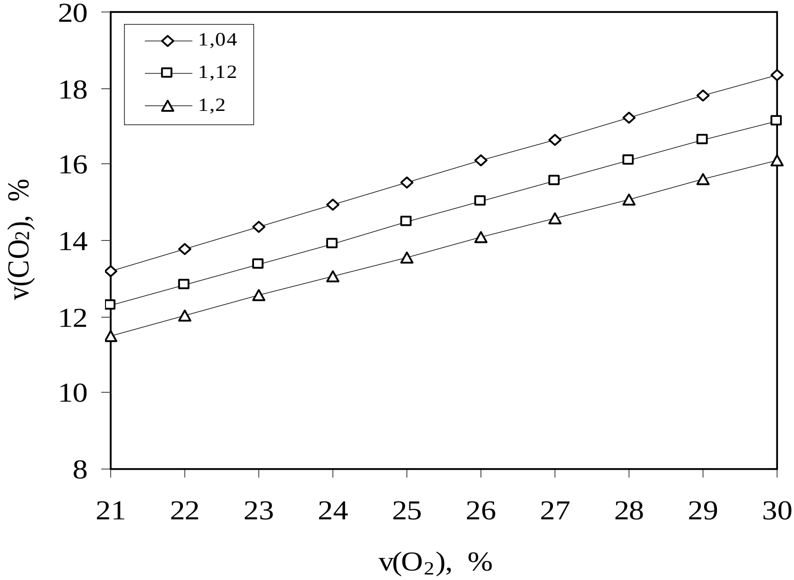

Figure 4. The content of CO_2 in combustion products as a function of air enrichment (λ = 1.00; 1.04; 1.08; 1.12; 1.16)

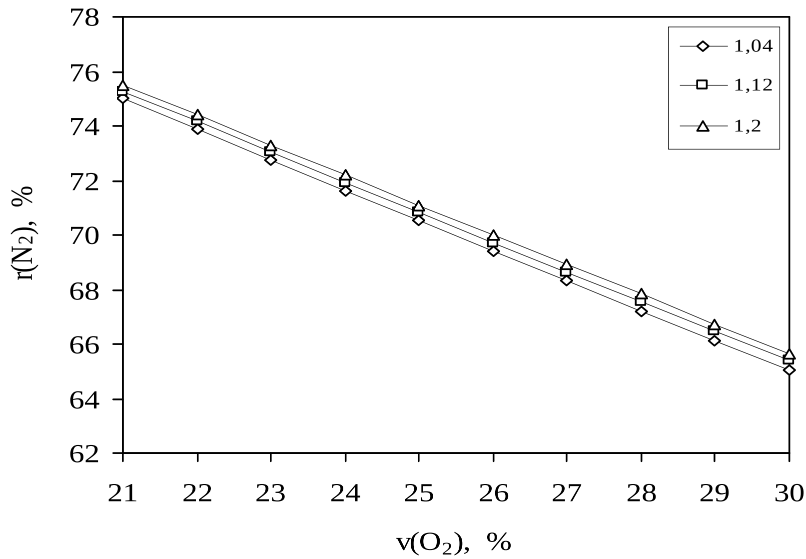

Figure 5. The content of N_2 in combustion products as a function of air enrichment (λ = 1.00; 1.04; 1.08; 1.12; 1.16)

The influence of the combustion air enrichment and the excess air ratio on the amount of combustion products, as well as on the chemical composition of combustion products (on O_2, CO_2 and N_2 content), were presented in form of 3D graphs, in Figures 6-8.

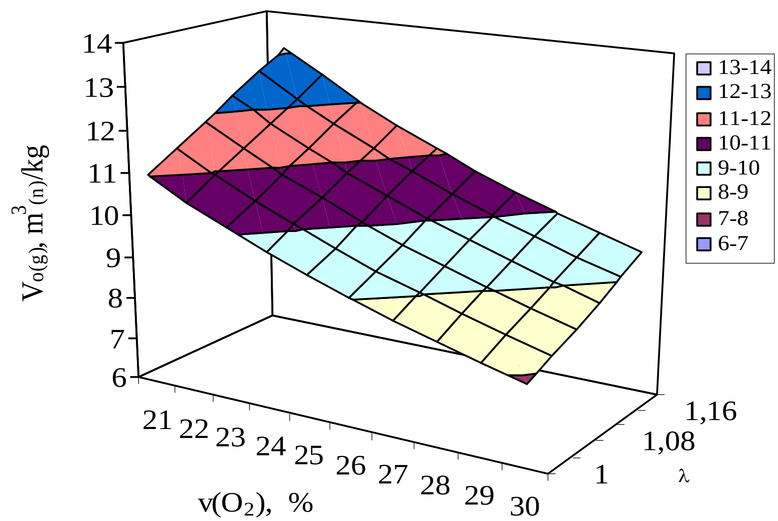

Figure 6. The effect of air enrichment and excess air ratio on the combustion products amount (3D-graph)

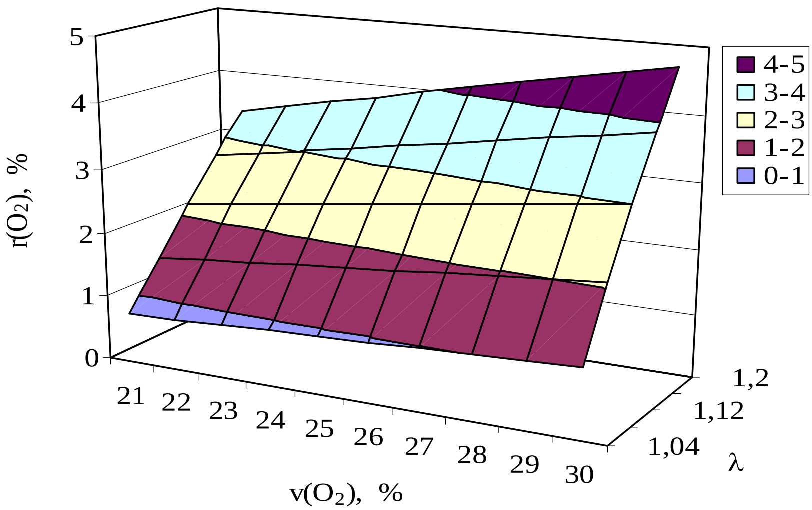

Figure 7. The effect of air enrichment and excess air ratio on oxygen content in combustion products (3D-graph)

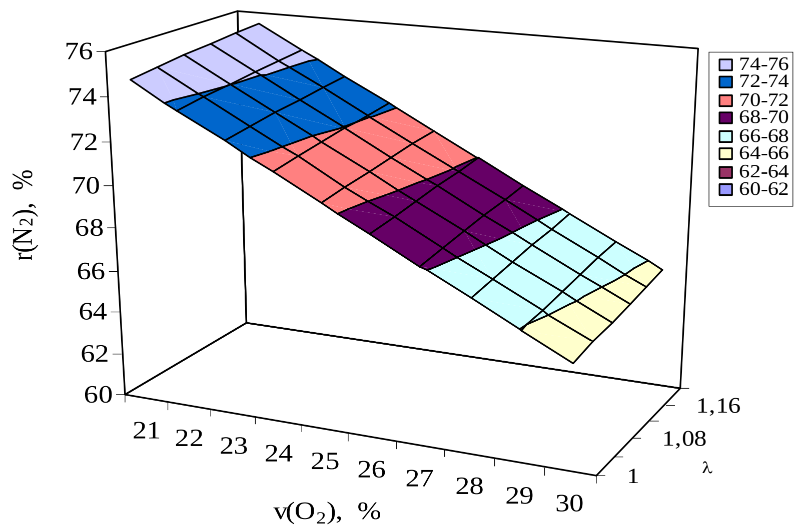

Figure 8. The effect of air enrichment and excess air ratio on nitrogen content in combustion products (3D-graph)

Mathematical expressions obtained as interpolation equations for calculating numerical values of the examined parameters of the heating process are shown in Table 2.

Table 2. Interpolation equations for determination of numerical values of examined parameters ($v(O_2)_m$ and λ_m are mean values of $v(O_2)$ and λ)

Parameter	Equations (y)	Variable (x)	Applied for
$V_{o(a)} = f(v(O_2))$	$y = 0.015\,x^2 – 0.545x+12.008$	$v\,(O_2)$= 21-30 %	$\lambda_{mean} = 1.10$
$V_{o(a)} = f(\lambda)$	$y = 0.349\,x + 8.365$	$\lambda = 1.0 – 1.20$	$v(O_2)_m$= 25,5 %
$V_{o(g)} = f(v(O_2))$	$y = 0.021\,x^2 – 0.604\,x+12.646$	$v\,(O_2)$= 21-30 %	$\lambda_m = 1.10$
$V_{o(g)} = f(\lambda)$	$y = – 0.0015\,x^2 + 0.367\,x+8.923$	$\lambda = 1.0 – 1.20$	$v(O_2)_m$= 25,5 %
$r(O_2)= f(v(O_2))$	$y = 0.0934\,x+2,0081$	$v\,(O_2)$= 21-30 %	$\lambda_m = 1.10$
$r(O_2)= f(\lambda)$	$y = 0.7755\,x+0,1948$	$\lambda = 1.0 – 1.20$	$v(O_2)_m$= 25,5 %
$r(CO_2)=f(v(O_2))$	$y = 0.549\,x+12,008$	$v\,(O_2)$= 21-30 %	$\lambda_m = 1.10$
$r(CO_2)= f(\lambda)$	$y = 0.0044\,x^2 – 0.3081\,x+16.674$	$\lambda = 1.00 – 1.20$	$v(O_2)_m$= 25,5 %
$r(N_2)= f(v(O_2))$	$y = – 1.1027\,x+76,281$	$v\,(O_2)$= 21-30 %	$\lambda_m = 1.10$
$r(N_2)= f(\lambda)$	$y = – 0.0053 + 0.184x+69.645$	$\lambda = 1.00 – 1.20$	$v(O_2)_m$= 25,5 %

CONCLUSIONS

The fuel combustion process is significantly affected by the amount of the combustion air and combustion products, air preheated temperature, oxygen enrichment air and waste gas temperature.
The performance of many air-fuel combustion processes can be improved by enriching the combustion air with oxygen. Oxygen enrichment of the combustion air increases both the flame temperature and the thermal efficiency of the furnace.
A key issue in combustion researches is the improvement in reduction of harmful emissions. An increase in oxygen content in the combustion results in a decrease of the amount of combustion products. The flue gas losses are reduced because the flue (waste) gas mass decreases as it leaves the furnace. So, there is less nitrogen oxide to carry heat from the furnace.
The increase of the oxygen content allows more stable combustion and higher combustion temperatures that can lead to a better heat transfer. Besides, when a furnace has been converted to be oxygen enriched, throughput can be increased for the same input of fuel because of a higher flame temperature, the increased heat transfer to the load, and a reduced flue (waste) gas.

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IZVOD

UTICAJ OBOGAĆIVANJA VAZDUHA NA KOLIČINU I SASTAV PRODUKATA SAGORIJEVANJA

(Originalan naučni rad)

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Performanse metalurških peći za zagrijavanje metalnih tijela, koje se lože tečnim ili gasovitim gorivom, mogu se poboljšati obogaćivanjem vazduha potrebnog za sagorijevanje. Povećanje sadržaja kiseonika u vazduhu, tj. obogaćivanje vazduha kiseonikom, ima poseban uticaj na smanjenje ukupne potrošnje goriva i energije. Obogaćivanje vazduha utiče na porast temperature plamena i toplotnu efikasnost peći. Konačni rezultat sagorijevanja goriva, u atmosferi vazduha obogaćenog kiseonikom, je promjena u sastavu produkata sagorijevanja, posebno smanjenje sadržaja N_2 (tj. oksida NOx), smanjenje potrošnje vazduha potrebnog za sagorijevanje, smanjenje zapremine izlaznih gasova i povećanje produktivnosti peći

U ovom radu su dati rezultati proračuna procesa sagorijevanja mazuta u uslovima rada kontinuirane peći za zagrijavanje čeličnih gredica. Predmet rada je analiza uticaja obogaćivanja vazduha na potrošnju vazduha, na sastav i količinu produkata sagorijevanja. Uslovi sagorijevanja su opisani promjenom vrijednosti koeficijenta viška vazduha (1,00 - 1,20), stepena obogaćenosti vazduha kiseonikom (21-30 %) i temperature gasova na izlazu iz peći (600 -1000 ^oC). Usvojena je konstantna vrijednost temperature predgrijavanja vazduha (400 ^oC), hemijski sastav goriva (elementarna analiza) i toplotna moć goriva.

Ključne riječi: sagorijevanje, obogaćenost vazduha kiseonikom, produkti sagorijevanja, emisija NO_x

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