Impact of oxygen enhanced combustion of natural gas on thermal efficiency of combustion aggregate

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Abstract. The aim of the present article is to present the achieved results on the experimental combustion aggregate. In the experimental measurement, the increased of the oxygen concentration in the oxidizing agent in the combustion of natural gas has been used. The results presented in this article are focused to achieve the thermal efficiency of the device, which is expressed by useful heat of the combustion aggregate. Part of the article is the analysis of the heating heat exchanger based on heat flow by convection and radiation and CFD mode of heat exchanger

1 Introduction

Energy efficiency control in industrial equipment has always been a relevant subject in industrial activity. In this context, there has been a lot of research in new methodologies and new processes of combustion control provided by the scientific community for technological development. Among researches, the industrial application of air combustion with oxygen enrichment has appeared in recent years (oxygen enhanced combustion). The recent technologies of oxygen production have enabled greater competitiveness of oxygen use for application in industrial combustion.

Baukal is the main structured reference on the oxygen enhanced combustion use. It is commented that the lowest levels of the enrichment (volumetric fractions of oxygen (O₂) in the combustion air below 30 %) are normally used in retrofit applications, in which only small modifications are necessary in the existing equipment. Moreover, expressive benefits are obtained with a significant increase in the production rate in processes of heating with low levels of enrichment. In most cases, burners can operate successfully using air of combustion air enriched with up to 28 % of oxygen, without modification in the equipment [1, 2].

Furthermore, Baukal Jr. showed that many industrial heating processes can be improved by substitution of part or total of the air with oxygen of high purity. Typical applications include heating and fusing of metals, fusing of glass and calcification. In a report from Gas

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Research Institute, the applications which were identified as possible candidates for the OEC: processes which have high exhaust temperatures and low thermal efficiency, due to constraints in the heat transfer typical in such conditions; processes with loading limitations, which could benefit from an additional heat transfer, without an adverse effect on the quality of the product; processes in which exhaust compounds are both in the gas and particle phases; processes with high NO_x emission rates and processes with limitations in the volume of the exhaust gases[1, 3].

2 Combustion aggregate

In order to assess the influence of the mentioned oxidizing agent properties on the combustion process, an experimental device (Figure 1) was constructed on which practical measurements were made. Within the measurements, a whirling burner burning natural gas using oxygen as an oxidizing agent at concentrations $\xi_1 = 21 \%$, $\xi_2 = 25 \%$, $\xi_3 = 30 \%$, $\xi_4 = 35 \%$ $\xi_5 = 40 \%$. In the case of individual measurements, a constant natural gas supply corresponding to a burner input of 9 kW and a surplus of oxidizing agent $m = 1.1$ was maintained. Enriching of the combustion air with oxygen was accomplished by injecting oxygen into the combustion air supply. The mixing of the natural gas with the oxidizing agent was carried out in the combustion chamber. The heat generated by combustion of natural gas was taken through a heat exchanger in which the cooling water flowed.

Fig. 1. Combustion aggregate Variant A.

The evaluation was developed into two design models. Variant A had a heat exchanger placed in the combustion chamber (Figure 1). In Variant B (Figure 2), the heat exchanger was moved away from the burner. The objective was to determine the effect of the flue gas temperature on the efficiency of the combustion aggregate. The flue gases in Variant B have a lower temperature than variants A due to thermal losses along the combustion chamber.

Fig. 2. Combustion aggregate Variant B.

2.1 Heat exchanger

Heat exchanger is a technical device that allows the exchange of heat between two substances. In assessing the effect of increased oxygen concentration in the oxidant to the combustion process, the heat released by the combustion of natural gas has to be transformed into useful heat item [4].

On Figure 3 shows a heat exchanger, this was used during laboratory measurements. This is a regenerative type of heat exchanger in which heat exchange takes place through a heat exchange surface. The heat exchange surface is formed by a steel tube bent in a spiral shape. The heat transfer in the exchanger is provided by a combination of convection heat flow and the heat flow caused by radiation.

Fig. 3. Description of heat exchanger.

The heat flux by convection is induced by flowing of the fresh combustion gases from the combustion around the heat exchange surface of the exchanger. However, flue gas as a heat transfer medium is characterized by a relatively small passage through the heat exchange surface of the heated body, therefore a high temperature of the flue gas is required in order to bring the temperature difference and the heat transfer as high as possible. The disadvantage of heating by exhaust gas is also the danger of local overheating of the exchanger and in the presence of oxygen in the exhaust gas also oxidation of the surface of the heat exchange surface. The heat flux is caused by an increased concentration of CO₂ and H₂O components in the flue as well as by radiation from the surface of the refractory material from the combustion and exchange section of the combustion aggregate.

The heat transfer medium in the heat exchanger was water. The water flow rate entering the exchanger was set so that the outlet heat exchanger temperature was below 50 °C. This condition was necessary due to possible thermal degradation of the hose, which served to drain water from the combustion aggregate.

2.2 Results

Based on experimental measurements, we can evaluate the effect of increased oxygen concentration in the oxidizing agent as follows. In Table 1 are plotted the results for variant A. Calculation of useful heat was given by the relationship:

$$Q_{,H2O} = m_{H2O} \cdot (c_{p,l2,H2O} \cdot t_2 - c_{p,l1,H2O} \cdot t_1)$$
 (1)

The calculation of the efficiency of the combustion aggregate is given by the relationship:

$$\eta = Q_{,H2O} / Q_{,c}$$
 (2)

Relationship (2) expresses the ratio between useful heat and total heat that has been brought to the aggregate.

Table 1. Results of useful heat for Variant A.

	21 %	25 %	30 %	35 %	40 %
t_1 (°C)	19.8	18.2	18.4	19.8	17.7
t_2 (°C)	45.8	46.2	47	48.1	47.3
m_{H_2O} (kg.h ⁻¹)	106.8	104	103.3	106	106.8
Q_{H_2O} (W)	3228.73	3385.89	3435.16	3491.30	3675.78
q_{H_2O} (W.m ⁻²)	9224.94	9673.99	9814.75	9975.15	10502.24
η (%)	38.47	39.96	40.81	41.71	43.72

Table 2. Results of useful heat for Variant B.

	21 %	25 %	30 %	35 %	40 %
t_1 (°C)	17.6	15.2	15.8	15.3	14.8
t_2 (°C)	36.9	35.6	36.7	35.8	36.9
m_{H_2O} (kg.h ⁻¹)	106.8	104	103.3	108.2	104
Q_{H_2O} (W)	2396.71	2466.87	2510.31	2579.11	2672.44
q_{H_2O} (W.m ⁻²)	6847.74	7048.19	7172.32	7368.89	7635.54
η (%)	28.72	29.57	29.77	30.38	31.60

The results presented in Table 1 and Table 2 confirm the positive effect of increasing the oxygen concentration of the oxygen in the oxidizing agent to the combustion process and to increase the efficiency of the combustion aggregate. However, the flue gas temperature decreases that the heat exchanger heating efficiency of Variant B is approximately 10 % lower than that of Variant A.

Figure 4 illustrates the effect of individual heat transfer processes on the heat exchanger depending on the concentration of oxygen in the oxidizing agent for both investigated variants. Heat transfer by convection decreases as a result of reduced flue gas production. Heat transfer through radiation is the dominant form of heat exchange, due to an increase in the concentration of the components CO₂ a H₂O.

Fig. 4. Type of heat transfer in combustion aggregate for Variant A and Variant B.

In order to visualize the influence of changing the heat exchanger storage in the combustion aggregate, a mathematical model was developed in ANSYS. Figure 5 shows the distribution of achieving temperature field in the outer surface of the heat exchanger.

Fig. 5. CFD model of heat exchanger.

3 Conclusion

The results of the experimental measurements confirmed the positive effect of the increased concentration of oxygen in the oxidizing agent on the thermal efficiency of the combustion plant. Increasing combustion temperatures intensifies the heat exchange in the heat aggregate and results in a faster heating of the batch material, thereby increasing furnace efficiency and decreasing the amount of consumed gas per unit amount of batch material. The submitted information is only partial results of the dissertation work.

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