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A STUDY ON EMISSIONS FROM AFTERBURNING CHAMBERS INCLUDED IN METALLURGICAL THERMAL EQUIPMENT

BADANIE EMISJI ZANIECZYSZCZEŃ Z KOMÓR DOPALANIA HUTNICZYCH URZĄDZEŃ CIEPLNYCH

Investigations on operational parameters of afterburning chambers included in metallurgical thermal equipment have been presented. The effects of temperature and modernization within the firing system on concentrations of nitrogen oxides and carbon oxide have been analysed. To ensure effective afterburning of gases generated during technological processes and minimisation of CO levels, the temperature in the afterburning chamber should be elevated to approximately 1053-1973 K with evenly distributed temperature within the flame. This may lead to slightly higher (by about 20 mg/m$_n^3$) NO$_x$ concentrations.

Keywords: afterburning chamber, nitrogen oxides, carbon oxide

Przedstawiono badania eksploatacyjne komór dopalania w hutniczych urządzeniach cieplnych. Przeanalizowano wpływ temperatury i działań modernizacyjnych w układzie opalania na stężenie tlenków azotu i tlenku węgla. Dla zapewnienia skuteczności dopalania gazów z procesów technologicznych i minimalizacji stężenia CO, należy zwiększyć temperaturę w komorze dopalania do ok. 1053-1973 K, przy zapewnieniu wyrównanego rozkładu temperatury w płomieniu. Może to spowodować nieznaczne podwyższenie stężenia NO$_x$ o ok. 20 mg/m$_n^3$.

1. Introduction

In technological devices, large quantities of low-calorific waste gases are generated. During a blast-furnace process, the amount of waste gases are assumed to be two-fold greater than the hot metal mass flow. As the gases contain a lot of toxic components and other, specific combustible substances, they must be destroyed during combustion processes. Technical parameters of process waste gases for selected cases are presented in Table 1 [1,2].

TABLE 1

Technical parameters of process waste gases [1,2]

Waste gas	Gas flow	Temperature	Dust level	Purification method	
				initial	final
		K	g m$_n^{-3}$	mg m$_n^{-3}$	
from varnish coating drying	about 32000 m$_n^3$ h^{-1}	about 533	about 5 organic compounds	no	no
from coal soot production	14000÷16000 m$_n^3$ h^{-1}	453÷503	<2 coal soot	no	no
blast furnace gas from shaft furnaces	about 180000 m$_n^3$ h^{-1}	about 333	about 98	a settling chamber 22-49; a multicell cyclone about 10-16	wet about 49-98
blast furnace gas	1200÷2000 m$_n^3$ Mg$_{hot\,metal}^{-1}$	about 473	about 60-80	dry, a stationary deduster	wet about 7-9
converter gas	50÷100 m$_n^3$ Mg$_{steel}^{-1}$	about 1473	about 100-140	no	wet about 70-90

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The calorific values of afterburning-subjected gases from technological processes (Table 2), e.g. from coating plant dryers, are low and do not ensure auto-thermal combustion [1,2]. Therefore, afterburning chambers must be additionally equipped with burners for enriched fuel combustion. Sizes of combustion and afterburning chambers depend on flows and parameters of technological waste gases as well as on environmental requirements, i.e. pollutant emission limits. In most cases, geometrical parameters of the chambers can be determined based on assumed volumetric thermal load and surface heat-flow intensity values.

Methods of process waste gas management [1,2]

Waste gas	Calorific value	Management method	
	MJ/m_n^3	co-combustion	a thermal device
from varnish coating drying	<1.34	natural gas	an afterburning chamber – domestic hot water (DHW) production
from coal soot production	1.5÷1.9	natural gas	an afterburning chamber – DHW production
blast furnace gas from shaft furnaces	1.8÷2.2	high-nitrogen natural gas (hard coal)	stoker-fired boilers
blast furnace gas	2.5÷3.2	gases: converter, enriched fuels, hard coal	heating furnaces, hot-blast stoves, double-fuel boilers
converter gas	about 6	with enriched gases and coal dust	recovery boilers, double-fuel boilers

As the primary objective of afterburning processes is effective and economical destruction of pollutants (not thermal energy production for technological processes), lower q_V° and q_A° limit values from Table 3 can be assumed [3,4].

Recommended thermal load values for combustion chambers [3,4]

Furnace type	Volumetric thermal load – q_V°	Intensity of heat-flow – q_A°	Notes
	kW m^{-3}	kW m^{-2}	
multi-layer furnace with a travelling-grate stoker	250 – 300	1 000 – 2 000	The value basically depends on the technological process parameters.
a pulverised coal-fired furnace	150 – 250	2 000 – 4 000	
boiler furnaces	300 – 350	3 000 – 5 000	
heating furnaces	100 – 300	*	*depending on the zone
recovery boilers**	200 – 230	8 000 – 9 000	**radiative – convective

Afterburning chambers are usually cylindrical. Their length and cross-section surface area are mainly determined by the time necessary for the reagents to remain within the recom-mended temperature zone, which is required for contaminant destruction [5]. The minimum length of time to remain in the chambers and the component afterburning is 0.3 to 1 sec. Afterburning emissions can be effectively reduced by means of the primary methods.

2. Identification of the technological process and the operating parameters of afterburners

For better resistance to corrosion, steel (and aluminium) sheets are coated with paints and enamels. The coatings are placed over hot-dip galvanised, previously degreased and chemically treated, steel strip with the use of a so-called coil coating method. The analysed technological line consisted of a 4-zone continuous drying furnace and co-operative combustion and afterburning chambers. The drying process results in required mechanical and operational parameters of steel sheets, while soluble fractions of varnishes undergo evaporation.

Flue gases, generated during natural gas combustion in chambers located next to the furnace, are continuously delivered to the furnace by a flue gas circulation fan. The flue gases are diluted with air which is drawn in through a hole placed in the wall perpendicular to the wall with a burner. At the same time, some flue gases and the varnish drying products are delivered from the furnace (on a recirculation basis) to the chambers where they are partly degraded and incinerated. Recirculation numbers and a composition of flue gases depend on the flow resistances in the flue which are a function of curtain settings and temperatures in the specific furnace zones.

In the combustion chambers, solvents are not completely incinerated so their thermal degradation must be completed with the use of afterburners at the final technological stage. As in the case of combustion chambers, afterburners are individually fired with gas. Afterburner flue gases autonomously preheat final drying products from the furnace and combustion chambers before their afterburning. Moreover, they release energy in a water heat exchanger that additionally supplies the central heating system.

More restricted limitations related to emission of most pollutants as well as partial wearing of technological equipment have resulted in modernization of the applied firing systems. For a typical technological process, the rate of varnish volatile fraction flow into flue gases is about 170 kg/h and the duration of drying process is approximately 40 seconds. A solution of varnish vapours and flue gases is delivered, together with the air, to the combustion chambers (on a recirculation basis) where it is combusted.

As the solvents are not completely combusted in the combustion chambers, they must undergo afterburning. The combustion chambers which produce flue gases for the drying furnace are fired with high-methane natural gas with a total flow of about 220-240 m_n^3/h to all 4 chambers. As each combustion chamber is equipped with only one diffusion block burner, the thermal power of one chamber and a burner is approximately 550-600 kW, not including the heat generated during incomplete combustion of the vapours. In a technological system of sheet coating, two afterburners (upper and lower)

were installed. The flow rate of natural gas that fuels a single afterburner is about 130-140 m_n^3/h. The vapours generated during the drying process are oxidisers for natural gas delivered to the afterburner. The oxygen fraction in the gases before afterburning is about 19-19.7%vol. Combustion products generated in the afterburner are cooled down to about 723 K in a recuperator located in the afterburner where, through the counter-flow mechanism, the vapours are heated up to 823 K before they are delivered to the burner [2].

3. Results of the study on afterburning of gases from technological processes

The technical characteristics of the afterburning chamber are presented in Figure 1 where CO and NO_x concentrations are shown (per 3% of oxygen in flue gases) as a temperature function [2]. The maximum recommended acceptable operational temperature of the afterburner is 1023 K. At this temperature, the assumed pollutant levels in flue gases are about 72 mg/m^3 and about 190 mg/m^3 for NO_x and CO, respectively. The assumed hydrocarbon level in flue gases, approximately 5 mg/m^3, corresponds to afterburning at about 1038 K, while the hydrocarbon level at 1023 K, determined from the technical characteristics, is approximately 7 mg/m^3. The temperature rise to about 1060 K promotes over two-fold CO level decrease from about 190 to 90 mg/m^3; however, this results in higher (by about 25%) NO_x levels.

A critical parameter affecting NO_x levels is the maximum temperature of the flame in the afterburning chamber. The ignition point of carbon oxide in a solution with dry air is about 923-1003 K. These values ensure that the temperature in the afterburning chamber is optimal for minimisation of carbon oxide levels in flue gases.

Small additions of water vapour decrease the carbon oxide ignition point by about 30-50 K which ensures lower temperature in the afterburning chamber and reduced nitrogen oxide levels [6].

The afterburning operational temperature should be a resultant of minimised thermal concentrations of nitrogen oxides and carbon oxide. The temperature in the afterburning chamber directly affects enriched fuel consumption, so it has a measurable economical effect.
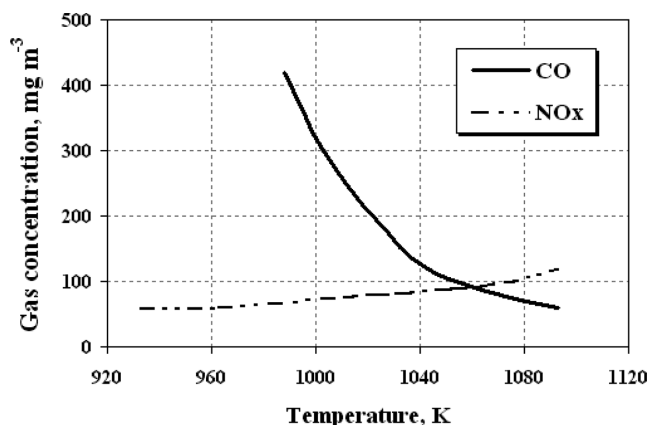

Fig. 1. CO and NO_x concentrations as a temperature function [2]

During the measurements, CO levels from the afterburning chambers of about 600-1600 mg/m^3 and NO_x levels of about 48-55 mg/m^3 were recorded – Fig. 2. The operational analysis of combustion chambers showed that the installed burner worked within about 25% of the nominal power. This resulted in small rates of the substrate flow from the burner and a lower ability to draw the mixture of vapours and flue gases, recirculated from the furnace, into the flame. Blending and combustion of vapours at high flame temperatures were also impeded by small rates of the gas flow into the combustion chambers (about 7.9 m/s). Location of the gas mixture inlet to the combustion chamber results in their boundary layer flow and poor draw into the flame zone, which leads to ineffective vapour combustion. Proper blending of both flows only occurs in a flue gas circulation fan where the temperature is not sufficient for vapour combustion.
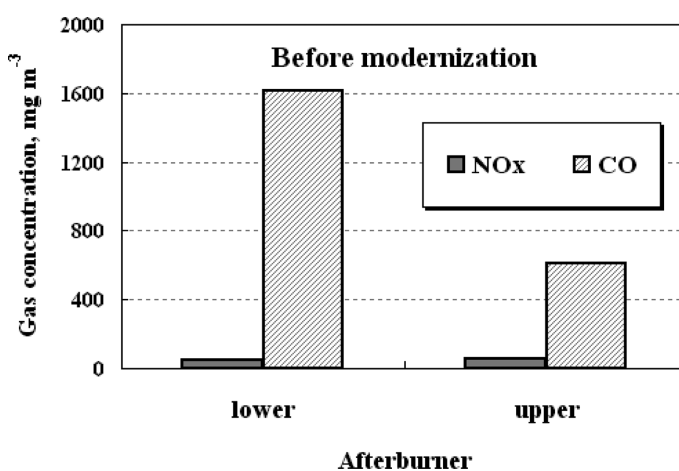

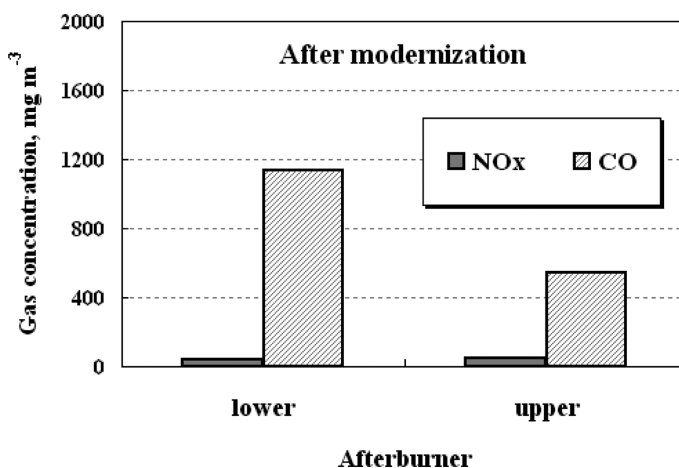Fig. 2. CO and NO_x concentrations in the lower and upper afterburners before modernization

Fig. 3. CO and NOx concentrations in the lower and upper afterburners after modernization

The analysis showed that to ensure lower levels of pollutants in afterburner flue gases, modernization of the afterburning chamber firing system was required. The modernization included: higher rates of flue gas flows from the technological line, substrate swirling flow implementation, a change in the configuration of outlet nozzles of the burner and vapours to induce better inner recirculation of the combustion substrates

as well as additional ceramic lining of the burner brick. This resulted in a lower maximum flame temperature and a better balanced flame temperature profile accompanied by a higher temperature at the ceramic brick outlet. CO and NO_x concentrations after modernization of the afterburner firing system are presented in Figure 3. The experiments were conducted at comparable afterburner operational temperatures, i.e. about 1000 K. The analysis of the findings showed that average concentration values decreased from 12.2 to 18.5% for NO_x and from 11.4 do 29.7% for CO. Despite the modernization, carbon oxide concentrations at 1023 K are still 3- to 6-fold higher than those assumed in the specification.

4. Summary

Due to a large variety of composition changes of substances delivered to afterburners, which result from the sheet coating technological parameters, a burner assessment with regard to hydrocarbon emissions is very difficult. In view of the flame thermokinetics, the assessment of afterburner burner can be performed based on the NO_x and CO concentrations. The quality of fuel and vapour combustion depends on geometrical, gas-dynamic and thermal parameters of the burner, the afterburning chamber design and the applied drying technology. Nitrogen oxide concentrations are reduced through decreasing maximum temperature of flames and the oxygen level within their volume. Intense flue gas recirculation in the flame zone results in lower levels of oxygen within the zone and a lower maximum temperature of the flame, which is an effect of more delayed combustion and inhibits NO generation. To ensure effective afterburning of gases from technological processes and minimisation of CO levels, the temperature in the afterburning chamber should be elevated to approximately 1053-1073 K with evenly distributed temperature in the flame. This may lead to slightly higher (by about 20 mg/m3$_n$) NOx concentrations.

Afterburning of waste gases from metallurgical processes is an important exploitation problem [7,8]. The above investigations may be partially replaced by modelling techniques with the use of CFD openFOAM software. Numerical modelling allows for prior determining the location and the method of oxidiser flow delivery without its negative effect on the technological process [9,10].

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