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Experimental Study of the Combustion Process of Gaseous Fuels Containing Nitrogen Compounds in New, Low-emission Zonal Volumetric Combustion Technology

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Abstract

The paper presents the result of experimental investigations of the innovative Zonal Volumetric Combustion technology (ZVC) applying several methods for toxic compound reduction (NO_X, CO and C_XH_Y) produced during the high combustion process of gaseous fuels in industrial combustion systems. In the ZVC technology, the volumetric combustion process of fuel takes place in two zones: the reducing zone and oxidizing zone.

The experimental studies included the influence of fuel-bound nitrogenous compounds like (NH_3, pyridine) on the overall emission of NO_X as well as the influence of high hydrocarbons (benzene) on CO, C_XH_Y and soot formation.

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1. Introduction

All new combustion technologies in the EU as well as in other countries have to fulfil new emission limits described in the EU directive and also other legislations, in particular: the Industrial Emission Directive (IED) [1] for Large Combustion Plants (LCP) entered into force on 1st January 2016 and to be further tightened under the Best Available Techniques conclusions (BAT) expected in 2020-2022 [2] and also in the Directive for Medium Combustion Plants

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(MCP) [3]. The emission limits for new and existing medium combustion plants of a firing power up to 50 MW are presented in Table 1. Other important regulations come from the current Energy Policy and upcoming perspectives, with the following targets (till 2030):

- reduction of greenhouse gases to 27%;
- increasing the share of renewable energy sources (RES) up to 30%,
- increasing the efficiency of energy conversion up to 27%,

compared with the 1990 levels.

Table 1. Emission limits for medium combustion plants according to MCP Directive.

-	Substance	Biomass	Other solid fuels	Natural gas	Other gaseous fuels	Heavy oil	Other liquid fuels
Existing plants[1]	SO_2	200	400	-	35	350	170
	NO_X	650	650	200	250	650	200
	Dust	30 (45 for ≤ 5 MW)	30	-	-	30	30
New plants[2]	SO_2	200	400	-	35	350	170
	NO_X	300	300	100	200	300	200
	Dust	20 (25 for ≤ 5 MW)	20	-	-	20	20

[1] Limits in force from 2030 for 1-5 MW firing power and from 2025 for 5-45 MW,
[2] Limits in force from 2018.

To fulfill these plans it is necessary to introduce high-efficiency and low-emission combustion technologies to energy and industrial sectors as well as fuels with a low ratio of CO_2 emission per kJ of produced energy called *low carbon fuels.* Such fuels are represented by gases with a high content of hydrogen and renewable fuels such as solid biomass, biofuels, biogas, syngas and waste gases. These kinds of fuels, especially syngas fuels, are characterised by a variable composition which depends on several factors like biomass composition [4, 5], operating conditions (temperature, pressure, residence time) [6, 7]; a type of gasifier [8, 9]; a gasifying agent [10, 11]. It causes that the amount of flammable components (methane, hydrogen and carbon monoxide), but also light unsaturated hydrocarbons (e.g. benzene, acetylene) and pollutants, such as nitrogen-containing compounds (e.g. ammonia, pyridine) and hydrogen sulfide, can vary widely. All the above mentioned fuel components influence syngas calorific value covering a wide range from 2 to 19 MJ/m^3.

The emission requirements as well as increasing energy conversion efficiency caused that the ICS Company designed and developed a new, low emission (mainly NO_X, CO and C_XH_Y) combustion technology for gaseous fuel utilisation called the Zonal Volumetric Combustion (ZVC) technology [12]. The ZVC technology is based on the same principles as the High Temperature Air Combustion (HiTAC) technology:

- intense internal flue gas recirculation;
- separate injection of air and fuel into the combustion chamber;
- preheating of air delivered to the combustion chamber;

but also introduces some significant changes such as:

- inside the combustion chamber where the volumetric combustion process takes place two zones are formed: the reducing zone and oxidizing zone;
- in the latter zone a high concentration of O_2 could occur;
- the upper part of the combustion chamber (reducing zone) has a trapezoidal cross section.

In the Zonal Volumetric Combustion Technology primary air and fuel are introduced into the combustion chamber in its upper part and are injected at a high speed. On the other hand, secondary air is introduced into the chamber in the middle of the chamber side surface with two rows of nozzles. Secondary air is injected also at a high speed to obtain aerodynamic separation of two combustion zones. Such division of air delivered to the combustion process divides the combustion process of fuels into two zones: an oxygen-deficient zone and a zone with oxygen excess. The scheme of the combustion chamber with marked combustion zones and gas and air flows is shown in Figure 1.

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