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HIGH TEMPERATURE TWO STAGE COMBUSTION CONCEPT FOR AMMONIA CONTAINED SYNGAS FUEL UTILIZATION

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Abstract: *This paper provides results of numerical study of synthesis gas combustion with special emphasis on fuel contained ammonia utilization. Ammonia is reference component of nitrogen contained particle and its influence on nitric oxides emission during combustion was investigated. The combustion process was performed with use of modern concept of High Temperature Air Combustion (HiTAC) technology called High Temperature Two Stage Combustion (HTTSC). The research was focused on numerical simulation of NO formation during this process. Numerical analysis of nitric oxides formation along the combustion chamber was conducted. Three numerical models were investigated using Cantera reaction kinetics environment; GRI 3.0, Tian and Konnov. The lowest emission rates were obtained for local air excess ratios* $\lambda = 0.45$ *and 0.6 on the first combustion stage. Absolute NO emission for GRI 3.0 was 24% higher than other mechanisms and trend for* $\lambda = 0.45$ *indicated greater emission than for 0.6. For all cases the final oxygen content in flue gases was kept at level of 7.9%. The results of numerical analysis indicated high compliance with experimental outcomes for high contents of ammonia in gas fuel.*

Keywords: syngas combustion, ammonia, nitrogen oxides

1. Introduction

Main obstacle facing the introduction of modern biomass gasification systems is gas derived contamination problem. Among a large group of undesirable synthesis gases compounds mainly tars as well as sulfur and nitrogen compounds can be distinguished (Neubauer, 2011; Surjosatyo, 2012; Asadullah, 2014). Ammonia is main nitrogen bounded component of synthesis gases produced in biomass gasification. In addition to the downstream applications of product gas treatment (chemical synthesis, hydrogen production etc.), ammonia is main precursor of nitrogen oxides formation during combustion. The typical ammonia content in synthesis gases cover the range from 200 to 5000 ppmv (Hongrapipat et al., 2012).

Numerical approach can be successfully applied to resolve fluid flows and emission problems(Bartoszewicz and Bogusławski, 2016; Urbaniak et al., 2015). Recent study on methane-air combustion with ammonia has shown that with the increase of NH_3 content in fuel gas the NO emission rise was not linear. Double increase of NH_3 share in the fuel lead to only 55.5% NO emission growth(Jójka and Ślefarski, 2018).

The present paper is aimed at numerical analysis of synthesis gas contained different content of ammonia combustion in semi industrial chamber with use of HTTSC technology to check compliance of numerical reactor models using different combustion kinetic mechanisms with outcomes of experimental research(Szewczyk et al., 2015).

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2. Research methodology

High Temperature Two stage combustion concept (HTTSC) is the next step of High Temperature Air Combustion (HiTAC) technology (called also flameless, mild or volumetric combustion) development. In HTTSC combustion takes place in two zones; reducing and oxidation. First, reducing zone is characterized by insufficient amount of oxygen conditions, while in second oxidizing zone excess of air is present. The simplified scheme of this system is displayed in Fig. 1.

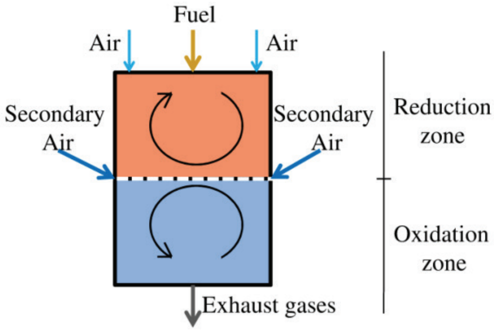

Fig. 1: Scheme of two stage combustion concept

The gas fuel and certain amount of preheated air (to keep excess of air ratio $\lambda<1$) is supplied to the upper part of combustion chamber from the top cover side. In this part reducing reactions are taking place which particularly allows to avoid nitric oxides formation because of the lack of oxygen and lower temperature. In the second step sufficient amount of air is delivered to the chamber as secondary air which leads to burning out the unburned reagents from first zone. The division of these two parts is realized aerodynamically through appropriate swirling of air stream from secondary air inlet and shape of combustion chamber. The detailed description and combustion characteristics were presented in previous articles (Szewczyk et al., 2015; Szewczyk, Ślefarski and Jankowski, 2017).

2.1 Fuel description and combustion configuration

For this study purpose one synthesis gas (with medium calorific value) composition with three different levels of ammonia covering the range from 500 to 5500 ppmv was investigated (SG01). Tab. 1 presents the composition with basic combustion parameters of this gas mixture. Because of air recirculation in considered combustion system the oxygen content in this chamber area is not zero. The average oxygen concentration in primary zone was calculated based on suction pyrometer gas composition distribution method results (Szewczyk et al., 2015). The resultant oxygen concentration correspond to air excess ratio $\lambda = 0.6$.

Tab. 1: Fuel composition (Szewczyk, Ślefarski and Jankowski, 2017)

Fuel name	**CO**	**CH_4**	**H_2**	**CO_2**	**N_2**	**NH_3**
SG01	7.6%	11.0%	11.7%	55.2%	14.5%	500, 2200, 5500 ppmv
Stoichiometric air demand		**Heating value**		**Air excess ratio in primary zone λ**		**Average air excess ratio for the system**
1.52 Nm^3 air/1 Nm^3 fuel		6.19MJ/Nm^3		0.6		1.6

2.2 Numerical model

The numerical computations were done using modified Cantera (Goodwin et al., 2017) code with use of two freely connected IdealGasReactors. First reactor was supplemented with stream of fuel SG01 and a part of the air stream, depending on the assumed conditions. Second part of the air was introduced into second reactor, where the further fuel oxidation takes place. Overall air stream was calculated as for $\lambda = 1.35$. Difference in kinetics between primary and secondary reactor was an effect of dividing amount of air into two zones (e.g. 0.45/0.9). Tests were made for range λ = 0.0-1.35, however idea of stage combustion is to maintain under and near stoichiometric conditions in the reduction reactor, while in the second one the excess air provides sufficient amount of oxygen to oxidize and complete the combustion process. In the first step of calculations the characteristics of NO formation for three combustion mechanisms GRI 3.0, (Smith et al.; Tian et al., 2009; Konnov and Ruyck, 2000; Konnov, 2009) were determined. In the second step, the extended study of combustion process for the highest ammonia content and reaction model outcomes corresponding to the most similar results of experimental investigations. This part has entered the calculations of temperature profile in these two reactors within the time of residence of reagents in reactions.

3. Results

In Fig. 2 the characteristics of NO emission depending on NH_3 content in the fuel for different λ and temperature characteristic of SG01 fuel combustion with ammonia content at 5500 ppmv level are shown.

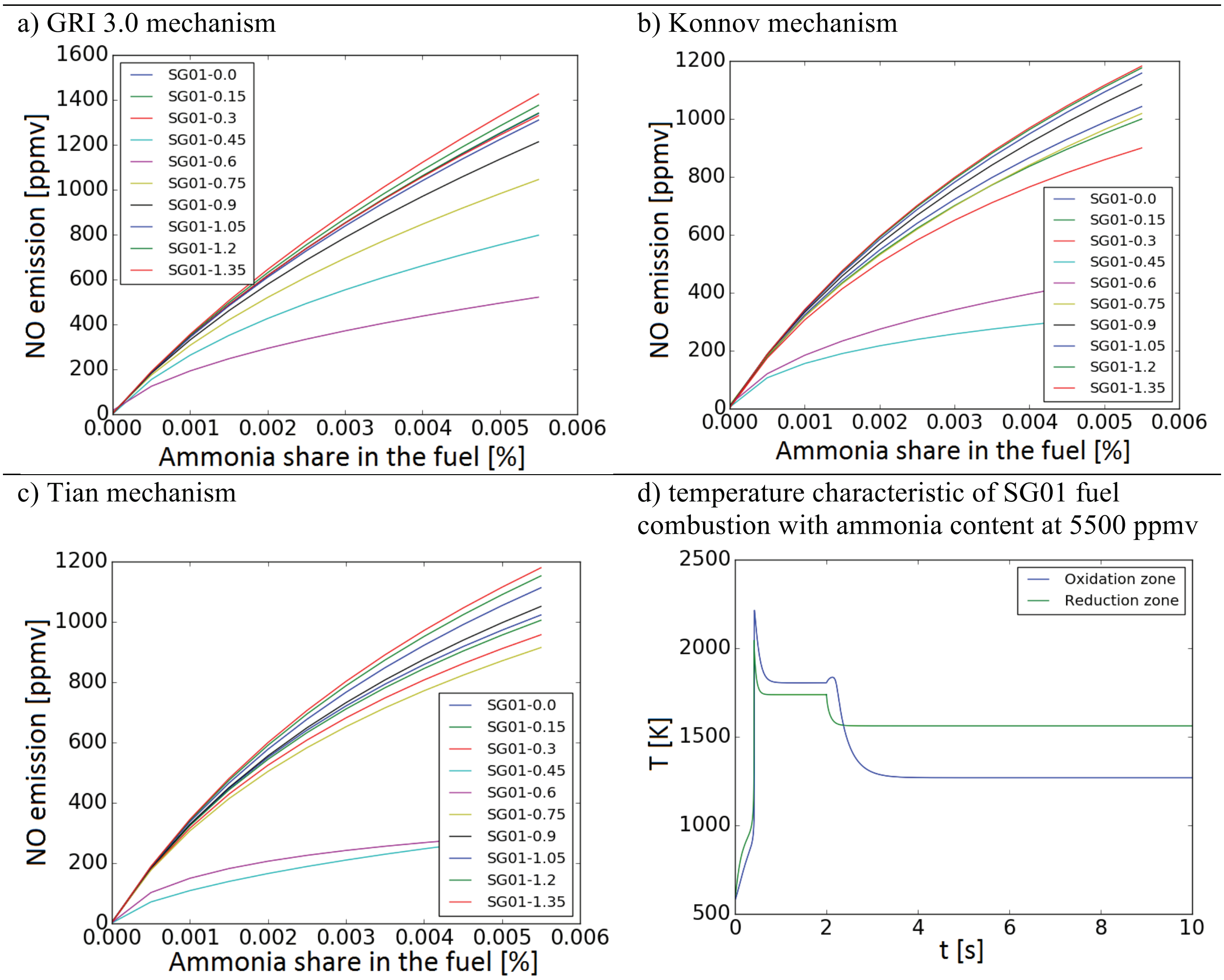

Fig. 2: The characteristics of NO emission depending on NH_3 content in the fuel for different air excess ratio a)GRI 3.0 mechanism, b) Konnov mechanism c) Tian mechanism, d) temperature characteristic of SG01 fuel combustion with ammonia content at 5500 ppmv level

The lowest resultant NO emission for GRI 3.0 was achieved for λ = 0.6 (approximately 450 ppmv) and λ = 0.45 for Konnov mechanism (326 ppmv). The lowest NO emission values were obtained for mid range local air excess ratios in the first reactor. In both cases the highest NO level was obtained for λ = 1.35. The results achieved according to Konnov mechanism are the most similar to experimental outcomes. In all investigated cases the fuel bounded ammonia (in NH_3) was not converted to that high amount of NO, which could be obtained in the oxidation process of NH_3 to NO.

For the increasing NH_3 content in syngas fuel the NO emission characteristics were not linear, with rising NH_3 content in the fuel relative NO emission intensity is decreasing.

As Konnov mechanism calculations results indicated high coincidence with experimental study in substoichiometric conditions for high NH_3 content, the detailed analysis of case with NH_3 equal to 5500 ppmv was performed. Obtained characteristic of temperature profile is presented in Fig. 2d.

Due to initialization approach, the peak of temperature at the beginning of reaction can be noted. In application of IdealGasReactor for considered parameters this occurrence has no influence on correctness of reaction. CH_4 and H_2 have higher combustion temperature and reaction rate (greater affinity for oxygen) in insufficient air excess conditions than CO. Therefore the rest of unburned components, mainly CO react in secondary zone. Additional calculations of particular compounds share within the reaction in both parts of combustion chamber (not presented in this paper) as well as higher temperature in primary zone (presented in Fig. 2d) confirm this contention.

Obtained optimal emission values of two stage combustion process could be compared to the border cases results. In the SG01-1.35 test all stream of air is provided with fuel to the first reactor. Furthermore, this situation simulates classical one stage combustion, what results in the highest relative NO emission. Second affordable to mention case SG01-0.0 described test where all of the air is delivered in the oxidation reactor and only thermal decomposition and recombination of fuel substrates could take place. Resultant NO emission outcome was similar in both cases, what gives information about oxidation of NO in the presence of oxygen and neglect able rates of straight NH_3 to N_2 reduction in the lack of oxidizer and promotes reduction process with NO as an intermediate species.

4. Conclusions

Based on obtained results following conclusions can be written:

- the lowest NO emission values were obtained for mid range local air excess ratios in the first reactor, air excess ratios 0.6 and 0.45, for all tests mechanisms the highest NO level was obtained for $\lambda = 1.35$,
- calculations with use of Konnov mechanism indicated the highest level of compliance with results of experimental analysis,
- with rising NH_3 content in the fuel relative NO emission intensity is decreasing
- high temperature two stage combustion allow to provide low NO emission from synthesis gases combustion as well as it is favorable approach to utilize high NH_3 contained gases without high NO emission.

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