

# Ammonia Oxidation Mixtures at High Pressure

Pedro García-Ruiz, Miguel Abengochea, Daniel Castejon, Rafael Bilbao, María Abián, María U. Alzueta,

Thermochemical Process Group (GPT), Department of Chemical and Environmental Engineering  
Aragón Institute of Engineering Research (I3A)  
Universidad de Zaragoza, Mariano Esquillor s/n, 50018, Zaragoza, Spain.  
Tel. +34-976762707, e-mail: p.garcia@unizar.es

## Abstract

Ammonia can be burned directly without CO<sub>2</sub> emissions, and it can be burned in mixtures with CH<sub>4</sub> and H<sub>2</sub>. The present work deals with the knowledge of the conversion at high pressures of NH<sub>3</sub> and its mixtures with CH<sub>4</sub> and H<sub>2</sub> as well as on the development of a suitable kinetic model able to describe the ammonia combustion process.

## Introduction

Nowadays, ammonia (NH<sub>3</sub>) plays an important role in decarbonization of energy resources because it does not produce carbon dioxide (CO<sub>2</sub>) emissions. Ammonia has been studied as an alternative fuel for several applications including energy storage, transportation and gas turbines [1, 2]. Ammonia represents a clean energy carrier because it is able to burn directly [3] producing water and nitrogen (N<sub>2</sub>) but, as a disadvantage, nitrogen oxides (NO<sub>x</sub>) can be formed from NH<sub>3</sub> oxidation [4]. Ammonia mixtures with hydrogen [5] and methane [6] enhance its combustion characteristics. Moreover, under certain conditions NH<sub>3</sub>-CH<sub>4</sub> mixtures emit less NO<sub>x</sub> than a NH<sub>3</sub>-air blend [7], and the experimental results indicate that a higher ratio of H<sub>2</sub> in NH<sub>3</sub>-H<sub>2</sub> mixtures improves its reactivity while does not an effect its emissions [8]. The present work pursues extending the knowledge of high-pressure oxidation of ammonia mixtures and the development of a detailed reaction kinetic model in order to describe the conversion of ammonia and its mixtures under wide range of operating conditions: oxygen excess ratio ( $\lambda$ ) from 1 to 3, pressure (from 10 to 40 bar), temperature (from 400 to 900°C), concentration of CH<sub>4</sub> and H<sub>2</sub> in the mixture.

## Methodology

Conversion of reactants and produced gas emissions from combustion of NH<sub>3</sub>, and its mixtures with CH<sub>4</sub> and H<sub>2</sub> are studied under well-controlled experimental conditions in an installation shown in figure 1. The present work is performed considering

the effect of main variables: stoichiometry, pressure, temperature and concentration of CH<sub>4</sub> and H<sub>2</sub> in the mixture. In the experiments, concentrations of NH<sub>3</sub>, CH<sub>4</sub>, H<sub>2</sub>, CO, CO<sub>2</sub>, hydrocarbons, NO, NO<sub>2</sub>, N<sub>2</sub>O and HCN will be analysed.

## Experimental results

Experimental results are obtained at specific conditions: 40 bar of pressure and a range of temperatures from 500°C to 900°C for each case: 1000 ppm of pure NH<sub>3</sub>, NH<sub>3</sub>-CH<sub>4</sub> mixture (1000 ppm for each component) and NH<sub>3</sub>-H<sub>2</sub> mixture (1000 ppm for each component).

The oxidation reaction of NH<sub>3</sub> at 40 bar started at 875°C for pure NH<sub>3</sub> and at 530°C for NH<sub>3</sub> mixtures for the selected conditions.

Figure 1 shows that most of ammonia does not react more than 10% at 900 °C. However, NH<sub>3</sub> in the NH<sub>3</sub>-H<sub>2</sub> mixture has reacted fully at 850°C and in case of NH<sub>3</sub>-CH<sub>4</sub> mixtures, full conversion of NH<sub>3</sub> approximately is reached at 600°C.

NH<sub>3</sub> oxidation only produced N<sub>2</sub>O significantly, Figure 2 shows that in the NH<sub>3</sub>-CH<sub>4</sub> mixture approximately twice as much N<sub>2</sub>O is produced compared to the NH<sub>3</sub>-H<sub>2</sub> mixture.

The oxidation reaction of NH<sub>3</sub> at 40 bar started at 875°C for pure NH<sub>3</sub> and at 530°C for NH<sub>3</sub> mixtures for the selected conditions.

## Conclusions

The results in this experimental study are summarised as follows:

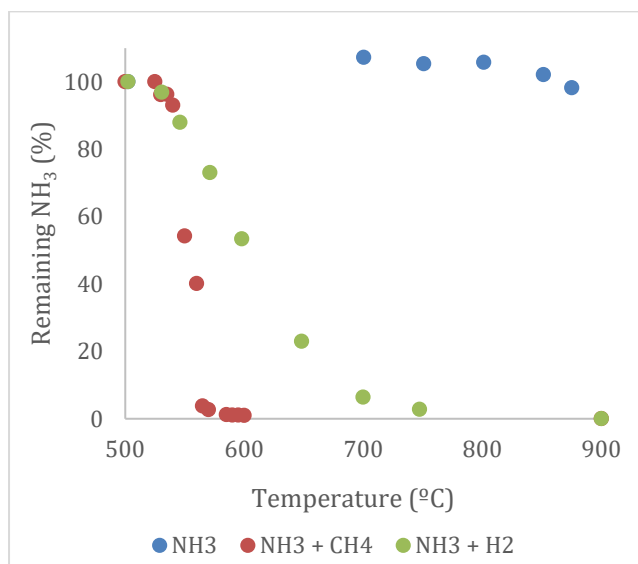
1. Oxidation reaction of NH<sub>3</sub> starts at lower temperatures, about 355°C before, for both NH<sub>3</sub>-CH<sub>4</sub> and NH<sub>3</sub>-H<sub>2</sub> mixtures compare to pure NH<sub>3</sub>.
2. Mixing NH<sub>3</sub> with CH<sub>4</sub> or H<sub>2</sub> improves reaction behaviour, consuming practically all the NH<sub>3</sub> at temperatures at which the oxidation of pure NH<sub>3</sub> has not yet started, but this mixtures oxidation present N<sub>2</sub>O emissions.

## ACKNOWLEDGMENTS

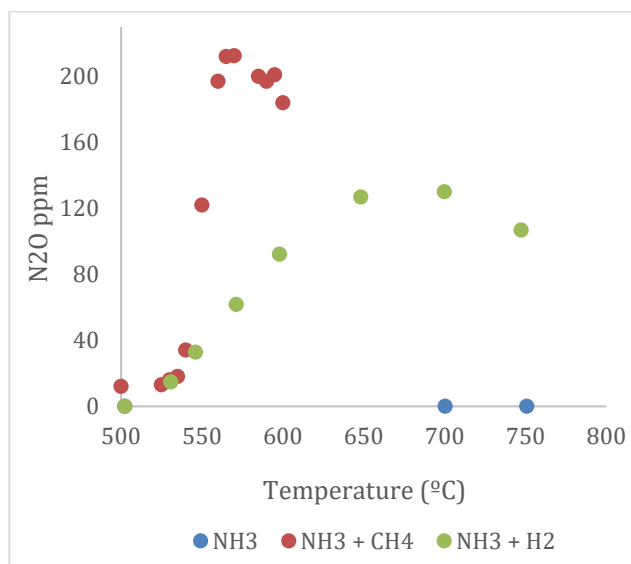
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**Figure 1: Comparison of remaining  $\text{NH}_3$ (%) at  $P=40$  bar,  $\lambda=3$  for different mixtures: 1000ppm  $\text{NH}_3$ , 1000ppm  $\text{CH}_4$  and 1000ppm  $\text{H}_2$  and 12,85 min of residence time.**



**Figure 2: Comparison of  $\text{N}_2\text{O}$  production at  $P=40$  bar,  $\lambda=3$  for different mixtures: 1000ppm  $\text{NH}_3$ , 1000ppm  $\text{CH}_4$  and 1000ppm  $\text{H}_2$  and 12,85 min of residence time.**