NOx Emissions From Intermediate-Temperature Combustion of Steel-Industry By-Product Gases

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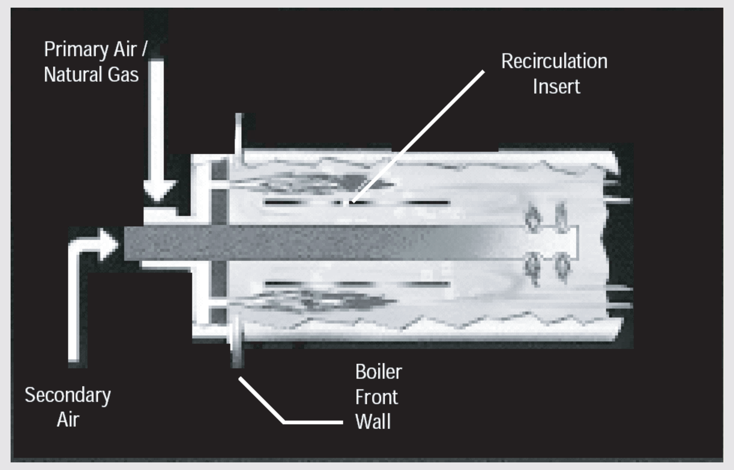
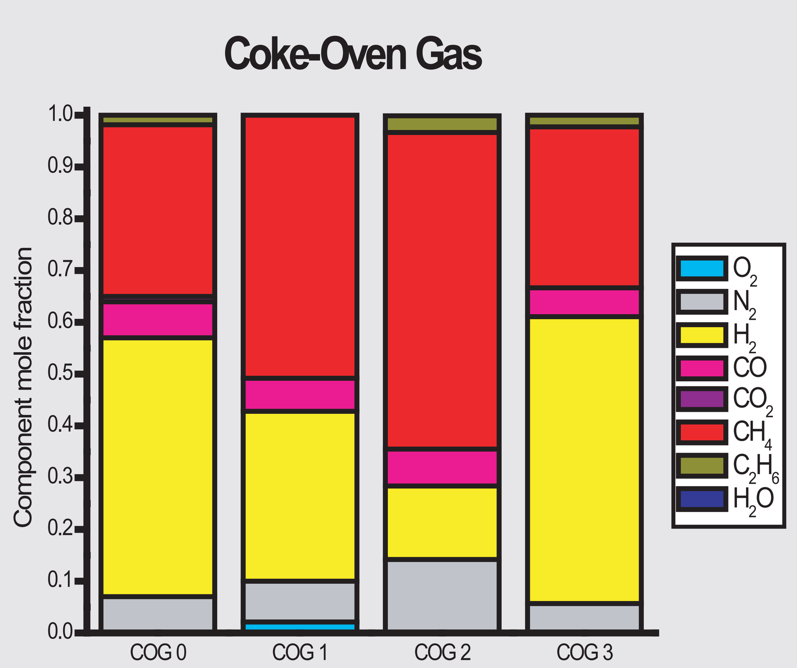
Introduction

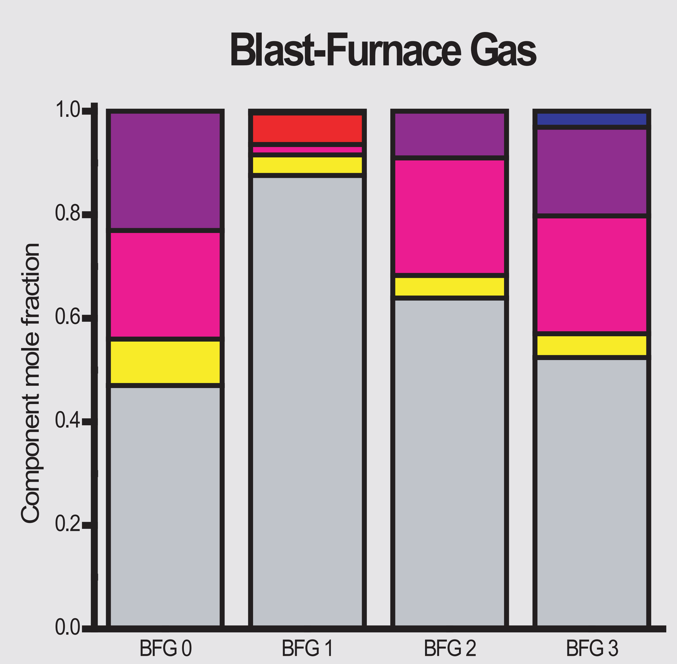
Investigations were made on NO emissions from low-BTU process off-gases available in the steel industry. The analysis focused on NO emissions under conditions of commercial ultra-low NOx, Forced Internal Recirculation (FIR) burner, where internal recirculation dilutes reactants and keeps the flame temperature in the range of 1200 - 1400 K.



By-product gases composition variability

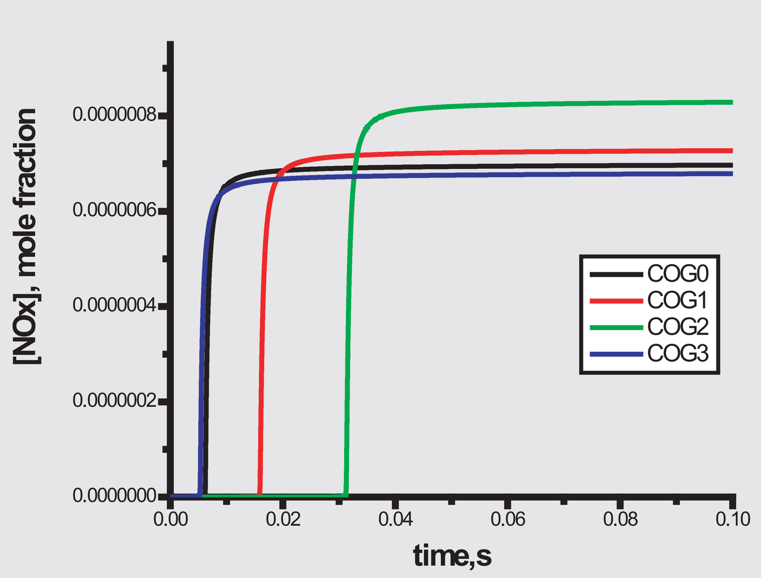
Coke Oven Gas (COG) and Blast Furnace Gas (BFG) are byproduct fuels generated by and utilized within the steelmaking industry. The composition of these fuels varies widely from plant to plant as shown in the graphs below.

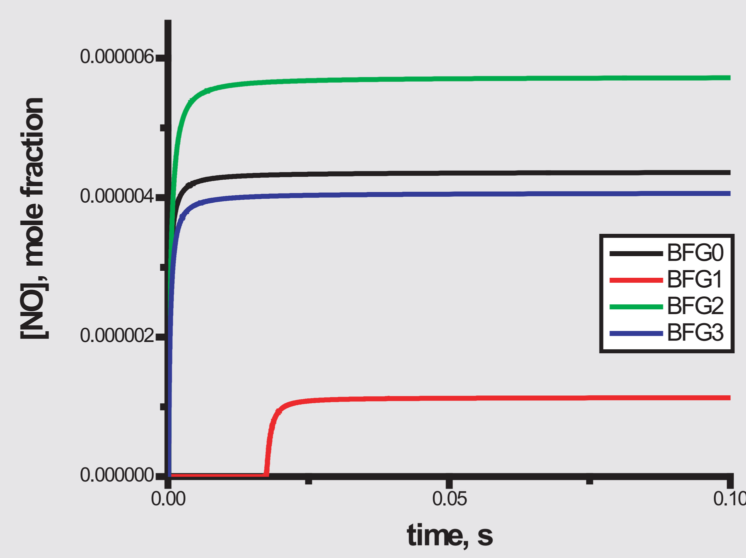




Resulting NOx emissions variability

BFG and COG Emissions during combustion were calculated at atmospheric pressure and 1200K. These are conditions found within the FIR burner, which is designed to achieve single-digit ppm NOx emissions without significant efficiency penalties. Simulation results are shown for ϕ = 1.0.



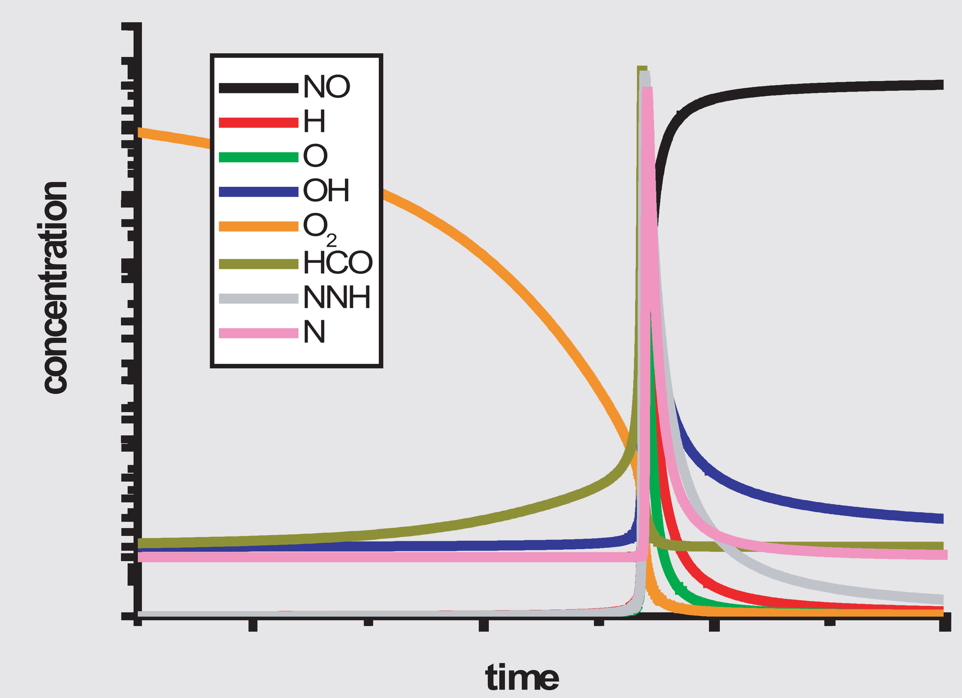


Observations:

- Difference in timing of NO appearance corresponds to the difference in ignition delay for different fuel blends.
- There is no net change of [NO] behind the flame front.

Both trends are in accord with the understanding that NO is formed only in the flame front, through the "prompt" mechanism. The thermal path (direct N2 oxidation) does not contribute significantly to NO formation due to the low temperatures.

Both points are illustrated for stoichiometric BFG 1 combustion at 1200 K and 1 atm:



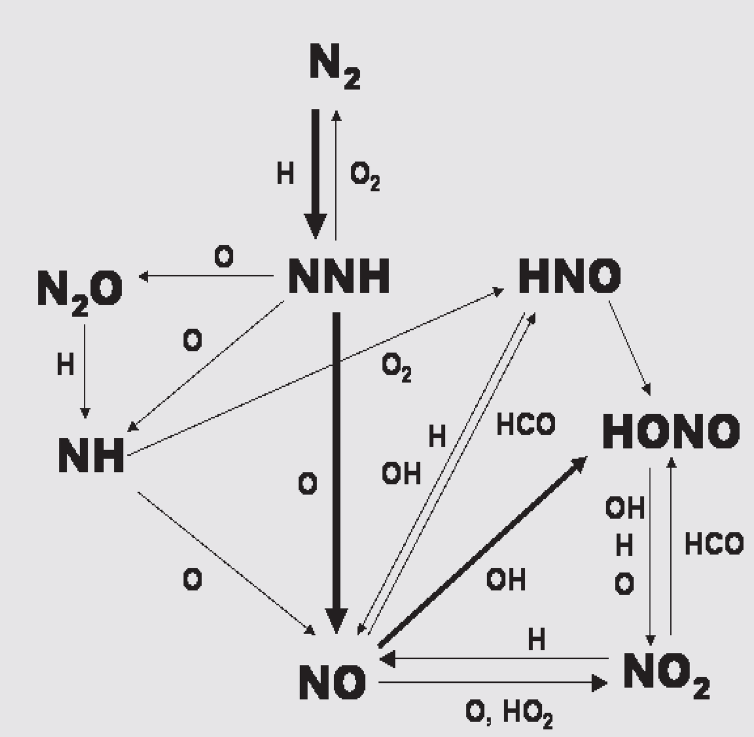
- Significantly lower NO emissions are predicted for combustion of BFG 1 than for other BFG blends.

BFG 1 is the only investigated blast furnace formulation that contains hydrocarbons. According to the widely accepted theory of Fenimore, hydrocarbon fragments, methylidene radical in particular, initiate NOx formation through:

$$N2 + CH = HCN + N$$

Fuel mixture producing CH radical is thus expected to produce most NOx, contrary to what our simulations predicted.

To resolve this apparent contradiction, pathway analysis was performed at the



Pathway analysis reveals that the N-N bond scission proceeds through reaction with hydrogen atom. Furthermore, methylidene radical was found to play an insignificant role in NO formation - NNH is the dominant pathway.

Pathway analysis confirms that there is no significant NO sink under the conditions of this study.

Implications:

The presence of hydrogen atom appears to control the N-N bond scission and, thus, NO formation at intermediate temperatures. This phenomena explains low NO emissions found with BFG 1. Thus, hydrocarbon fuel components control the hydrogen atom availability through:

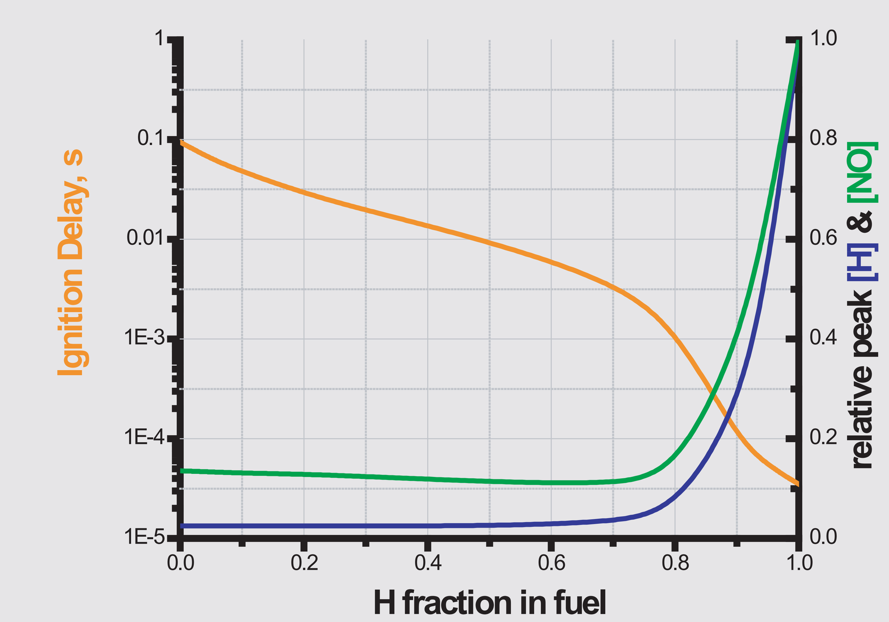
$$CH4 + H = CH3 + H2$$

$$C2H6 + H = C2H5 + H2$$

$$C2H5 + H = C2H4 + H2$$

Replacing hydrogen atom by much less reactive methyl and ethyl radicals, hydrocarbon presence also postpones ignition as was found with BFG 1.

It was determined that there exists an optimum quantity of natural gas presence in BFG for minimum NO emissions. The optimum was found through simulation of combustion of H2 - natural gas mixtures ranging from pure natural gas to pure H2.



Besides reducing NO emissions, natural gas could also help in BFG combustion by stabilizing this low-BTU flame.

An experimental program is currently underway to confirm the H/CH4 interaction found in this study.

References

1. Djurisic Z. M. and Eddings G. E., "Selection of detailed chemical kinetic model for the simulation of nitrogen oxide chemistry during natural gas combustion at Intermediate temperatures", final report for the Gas Technology Institute, subcontract No. PF8680, November 2002.

2. Djurisic Z. M., Eddings E. G., NOx emissions from intermediate-temperature combustion of steel-industry by-product gases, to be presented at the 3rd Joint meeting of the US Sections of the Combustion Institute

Acknowledgements

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