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Effect of Syngas Composition on Emissions from a Swirl Burner

Christopher Shaddix, Timothy Williams,
and Robert Schefer

Combustion Research Facility
Sandia National Laboratories
Livermore, CA 94550
USA

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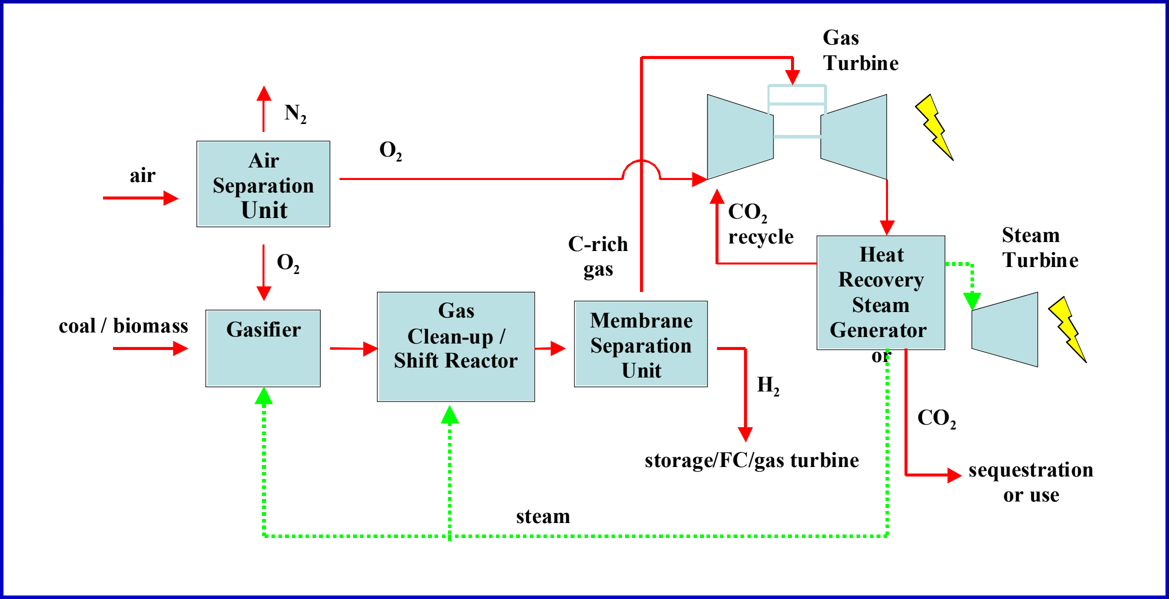
Abstract

Co-production of electrical power and gaseous or liquid fuels from the gasification of coal or biomass will likely require gas turbine operation on unusual fuel mixtures. In addition, global climate change concerns may dictate the production of a CO_2 product stream, likely impacting the oxidizer used in the gas turbine. In this study the operation of an optically accessible swirl-stabilized premixed combustor, burning fuels ranging from pure methane to conventional and H_2-rich and H_2-lean syngas mixtures is investigated at 1 atm. Both air and CO_2-diluted oxygen are used as the oxidizers. CO and NO_x emissions for these flames have been determined over the full range of stoichiometries from the lean blow-off limit to slightly rich conditions ($\varphi \sim 1.03$).

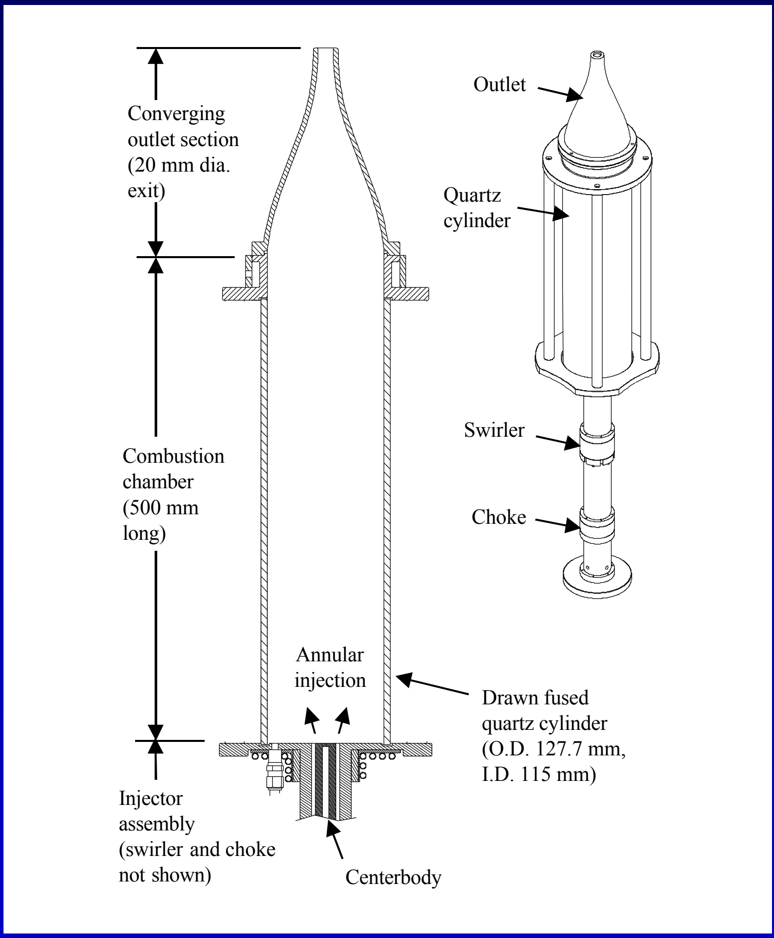
The presence of hydrogen in the syngas fuel mixtures results in more compact, higher temperature flames, resulting in increased flame stability and higher NO_x emissions. The lean blowoff limit and the lean stoichiometry at which CO emissions become significant both decrease with increasing H_2 content. CO emissions near the stoichiometric point do not become significant until $\varphi > 0.95$. At this stoichiometric limit, CO emissions rise more rapidly for combustion in O_2-CO_2 mixtures than for combustion in air.

Background

- Abundant reserves of coal in U.S. and in the world ("200-year" supply)
- Extensive biomass production capability
- Production of syngas from oxygen-blown gasifiers allows routes to gaseous and liquid fuel production, potentially with CO_2 capture
- Co-production of electricity and fuels is most energy efficient way to generate fuels
- Details of co-production scheme effect fuel and oxidizer composition used in gas turbine



Experimental Setup: Optically-Accessible Swirl Burner



- 1 atm
- premixed reactants
- choke inlet for acoustic decoupling
- swirler: 45° outlet vanes, S = 0.87
- 16 m/s flow inlet, Re ~ 22,000
- quartz chimney
- converging outlet section with small exit aperture (prevents 'tornado' effect)
- well-defined boundary conditions (for LES modeling)

Exhaust Gas Analysis System

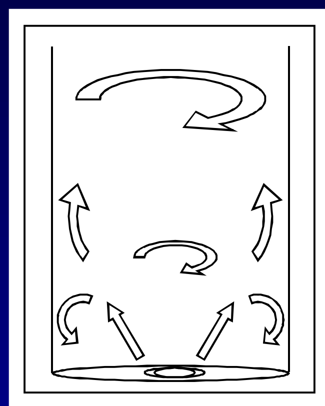
- CO -- NDIR
- NO_x – chemiluminescent
- O_2 -- paramagnetic

Gas Compositions Investigated

Fuel	Fuel Composition (% vol.)					H_2/CO Ratio	LHV
	CH_4	H_2	CO	N_2	CO_2		MJ/Nm^3
Methane	100	-	-	-	-	-	32.8
Slurry feed syngas	-	35	50	1	14	0.70	9.2
Dry feed syngas	-	28	64	5	3	0.44	10.2
H_2-lean syngas	-	1	76	2	21	0.013	8.9
H_2-rich syngas	-	95	1	3	1	95	9.5

Fuel	Oxidizer (% vol.)				φ range	Power (kW)	T_{adiab} (K)
	Air	O_2	N_2	CO_2		@ φ = 0.7	@ φ = 0.7
Methane	100	-	-	-	0.64 → 1.03	10.5	1839
Slurry feed syngas	100	-	-	-	0.36 → 1.05	11.1	1998
Dry feed syngas	100	-	-	-	0.35 → 1.05	11.5	2063
H_2-rich syngas	100	-	-	-	0.25 → 0.70	10.4	1999
Methane	-	30	1	69	0.58 → 1.06	14.6	1839
Methane	-	34	1	65	0.50 → 1.05	16.3	1996
Slurry feed syngas	-	30	1	69	0.35 → 1.02	14.3	1990
Slurry feed syngas	-	34	1	65	0.31 → 1.03	15.5	2118
H_2-lean syngas	-	30	1	69	0.44 → 1.02	14.6	1983
H_2-lean syngas	-	34	1	65	0.38 → 1.03	15.9	2105

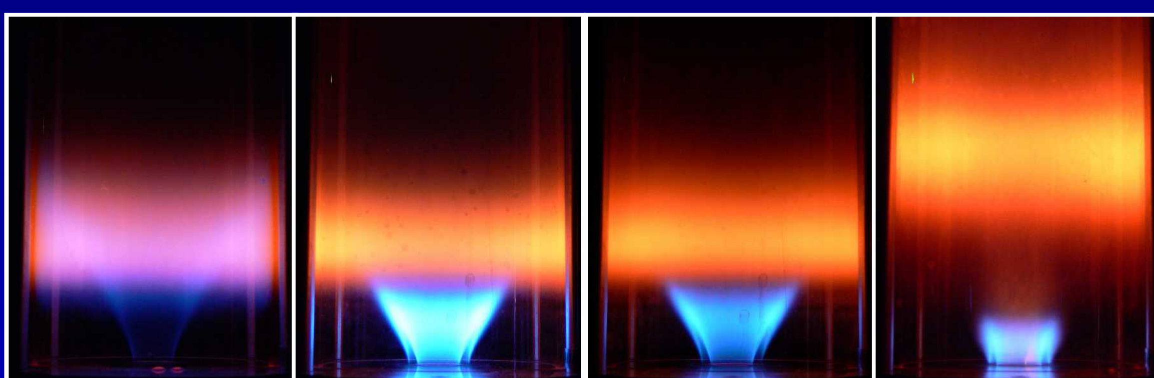
Flame Photographs



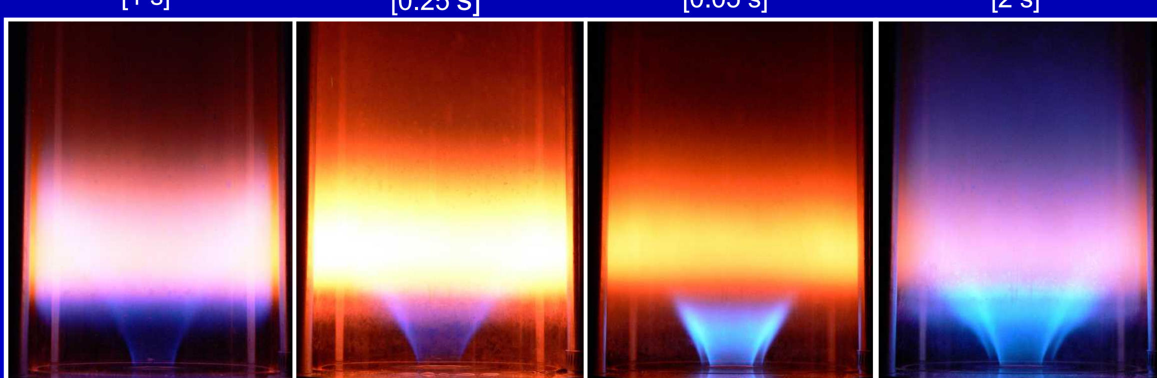
flow patterns in combustion chamber

($\varphi = 0.70$)

glowing quartz wall



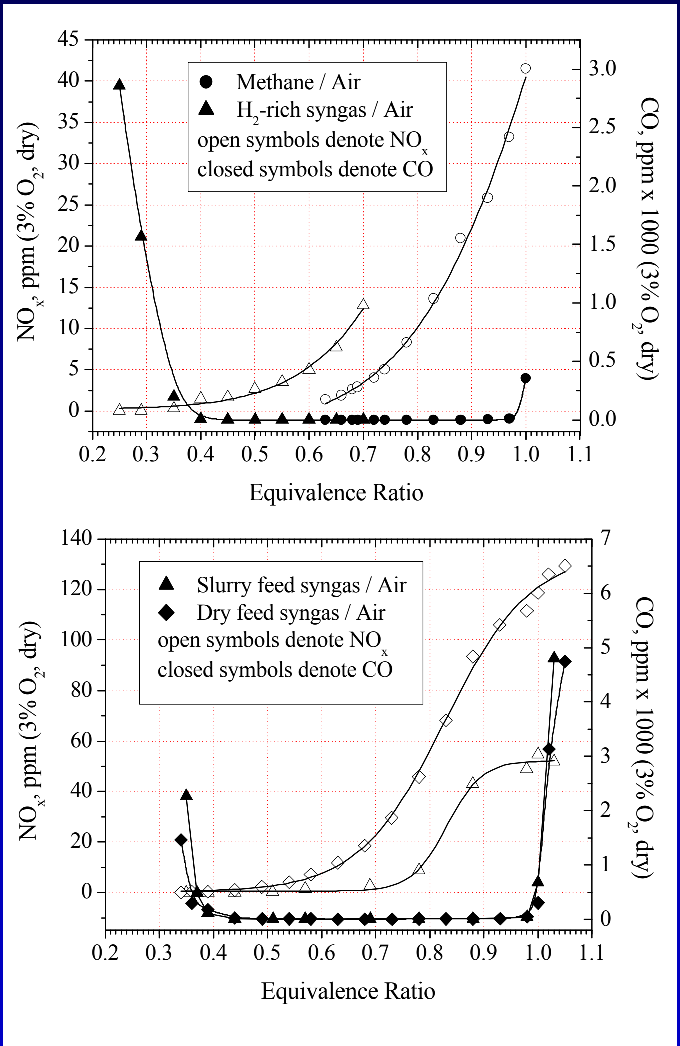
Methane/Air [1 s] | Slurry feed syngas/Air [0.25 s] | Dry feed syngas/Air [0.05 s] | H2-rich syngas/Air [2 s]



Methane/30% O_2-CO_2 [1 s] | Methane/34% O_2-CO_2 [0.25 s] | Slurry feed syngas/ 30% O_2-CO_2 [0.05 s] | H_2-lean syngas/ 30% O_2-CO_2 [0.05 s]

Emission Trends for Combustion in Air

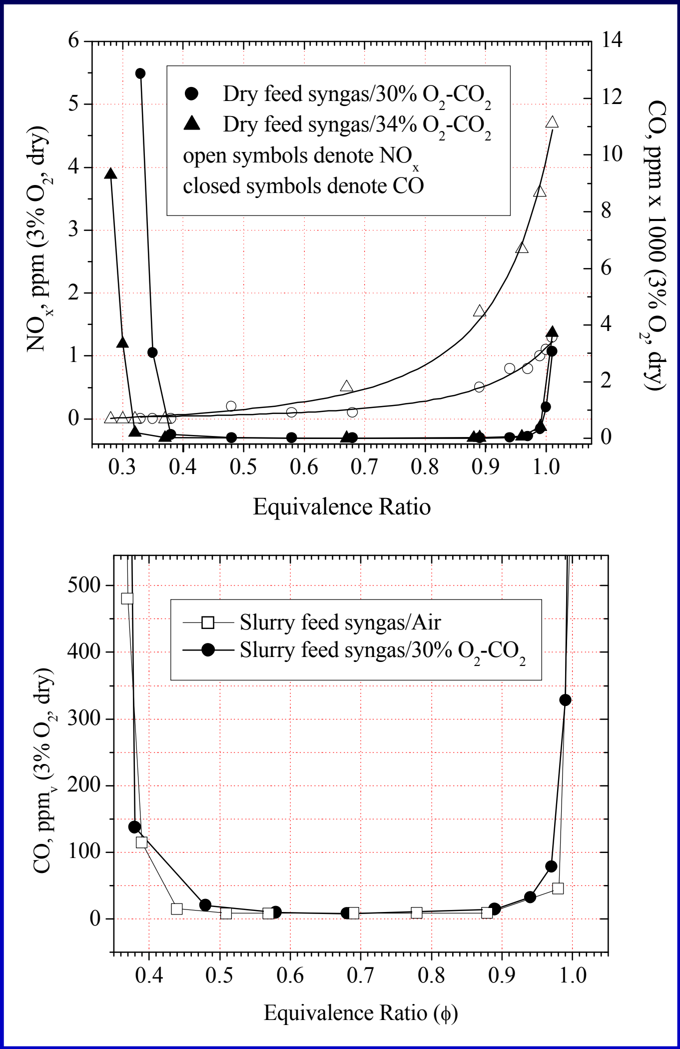
NO$_x$ and CO versus Equivalence Ratio



- Presence of H_2 increases stability (allowing leaner operation) and increases NO$_x$ emissions for a given φ

Emission Trends for Combustion in O_2/CO_2

NO$_x$ and CO versus Equivalence Ratio



- Low NO$_x$ emissions for all stoichiometries
- CO emissions rise at lean blowoff and for $\varphi > 0.95$, where one would like to operate (to minimize oxygen use)

Conclusions

- Trends in lean blowoff and CO and NO_x emissions have been measured in swirl burner for wide range of fuel and oxidizer mixtures
- Increasing H_2 content in syngas increases flame speed (compactness), stability, and NO_x emissions
- In O_2/CO_2 combustion system, NO_x emissions are very low and CO emissions are negligible until equivalence ratio exceeds 0.95

Acknowledgments

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