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Key Combustion Issues Associated with Syngas and High-Hydrogen Fuels

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3.1-1 Key Combustion Issues Associated with Syngas and High-Hydrogen Fuels

Combustion of syngas and high-hydrogen fuels requires attention to key combustion issues, especially if low emissions are to be achieved using these fuels. Current combustion systems operated on natural gas have evolved to the point where low single digit NOx emissions are possible with lean premixed strategies. However, the price of this evolution has been a significant increase in sensitivity to various perturbations such as changes in ambient conditions and variation in pipeline natural gas composition. In light of these observed sensitivities, strategies over an above lean premixed are continuing to be evaluated as discussed in "Combustion Strategies for Syngas and High Hydrogen Fuel". To reduce risk and development time, it is desirable to apply the experience of developing low emissions combustion systems for natural gas to syngas and high-hydrogen fuels. However, the range of compositions found in syngas and high-hydrogen fuels varies more substantially than similar properties of pipeline natural gas. By way of example, consider the ranges of composition shown in Table 1. Table 2 summarizes the range and average values of the fuel constituents shown.

As a result of the wider range of composition found in syngas and high hydrogen fuels, strategies well suited for low emissions performance on natural gas may not necessarily work best for syngas and hydrogen containing fuels. That said, it is important to note that the variation indicated in Table 1 and Table 2 is somewhat misleading. Specifically, if a given feedstock and gasifications process is considered, the variation found will be much less. By way of example, if the processes are limited to PSI Wabash, Tampa, El Dorado, and Motiva, a representation of variation found in coal/pet coke fed, oxygen blown gasification systems can be established as illustrated in Table 3.

The other point to be made by way of introduction is that hydrogen poses the most significant challenge in terms of the combustion system. As a fuel, hydrogen behaves differently than a hydrocarbon in many ways including specific heat (hydrogen has a much higher specific heat than other gases), diffusivity (hydrogen has a much higher diffusivity than other gases), flammability limits (hydrogen has a wide range of volume concentrations over which it is flammable), and flame speed (hydrogen has a much higher laminar flame speed than do other gases). As a result, the presence of hydrogen creates issues for combustion that require a different perspective than would a hydrocarbon fuel. Further, mixtures of gases often exhibit non-linear behavior and little data are available on the types of mixtures found in syngas.

With this in mind, the key issues that are associated with combustion of syngas and hydrogen containing fuels can be broadly classified into two major areas: reaction location and stability. These two areas are discussed in detail in "Static and Dynamic Stability".

Reaction location is an issue for all strategies and is related to the chemistry and time scales associated with the system. In strategies which involve premixing the fuel and oxidant (especially for lean strategies), the possibility of reaction evolving into the premixing region is a major concern. Given the high flame speeds of hydrogen, this concern must been examined carefully. Another issue related to the reaction location is ignition delay. With 1-5 msecs of premixing time available, at typical gas turbine inlet temperatures and pressures, ignition delay does not appear to be a major concern for the fuels of interest—however, the predictions of ignition delay have been developed largely in the absence of data at these conditions. As a result, better understanding of whether autoignition might be a factor is really needed to confirm this expectation.

Stability can broadly be divided between static and dynamic regimes. It is often reasoned that the wide flammability limits of hydrogen can allow stable operation at leaner (and therefore cooler) reaction temperatures. This extension of the lean blow off or static stability limit is an inherent benefit that should be realized from the presence of hydrogen. However, the extent to which this limit can be achieved in practice and, furthermore, its sensitivity to variation in composition is a key issue. On the other hand, dynamic stability, which is less predictable than static stability, can arise for combustion systems due to various reasons. How fuel composition impacts the propensity of a system to exhibit dynamic stability issues is another concern that must be addressed.

Table 1 Typical Syngas Compositions.[1]

Constituents	PSI	Tampa	El Dorado	Pernis	Sierra Pacific	ILVA	Schwarze Pumpe	Sarlux	Fife	Exxon Singapore	Motiva Delaware	PIEMSA	Tonghua
H_2	**24.8**	**37.2**	**35.4**	**34.4**	**14.5**	**8.6**	**61.9**	**22.7**	**34.4**	**44.5**	**32**	**42.3**	**10.3**
CO	**39.5**	**46.6**	**45.0**	**35.1**	**23.6**	**26.2**	**26.2**	**30.6**	**55.4**	**35.4**	**49.5**	**47.77**	**22.3**
CH_4	1.5	0.1	0.0	0.3	1.3	8.2	6.9	0.2	5.1	0.5	0.1	0.08	3.8
CO_2	**9.3**	**13.3**	**17.1**	**30.0**	**5.6**	**14.0**	**2.8**	**5.6**	**1.6**	**17.9**	**15.8**	**8.01**	**14.5**
N_2+AR	2.3	2.5	2.1	0.2	49.3	42.5	1.8	1.1	3.1	1.4	2.15	2.05	48.2
H_2O	22.7	0.3	0.4	---	5.7	---	---	39.8	---	0.1	0.44	0.15	0.9
LHV													
BTU/ft^3	209	253	242	210	128	183	317	163	319	241	248	270.4	134.6
kJ/m^3	8224	9962	9528	8274	5024	7191	12492	6403	12568	9477	9768	10655	5304
T_{fuel} , F	570	700	250	200	1000	400	100	392	100	350	570	338	---
T_{fuel} , C	300	371	121	98	538	204	38	200	38	177	299	170	---
H_2/CO	**0.63**	**0.8**	**0.79**	**0.98**	**0.61**	**0.33**	**2.36**	**0.74**	**0.62**	**1.26**	**0.65**	**0.89**	**0.46**
Diluent	steam	N_2	N_2/steam	steam	steam	---	steam	moisture	H_2O	steam	H_2O/N	N_2	n/a
Equivalent LHV													
BTU/ft^3	150	118	113*	198	110	---	200	---	*	116	150	129	134.6
kJ/m^3	5910	4649	4452	7801	4334	---	7880	---	---	4600	5910	5083	5304

* Always co-fired with 50% NG

Table 2 Summary of Compositions

Constituent	Volume %		
	Min	Max	Avg
Hydrogen	8.6	61.9	31.0
Carbon Monoxide	22.3	55.4	37.2
Methane	0	8.2	2.2
Carbon Dioxide	1.6	30	12.0
Nitrogen + Argon	0.2	49.3	12.2
Water	0.1	39.8	7.8
Hydrogen/Carbon Monxide Ratio	0.33	2.36	0.86

Table 3 Composition Variation for Pet Coke/Coal Fired, Oxygen Gasified Fuel Streams.

Constituent	Volume %		
	Min	Max	Avg
Hydrogen	32	37.2	34.6
Carbon Monoxide	45	49.5	47.3
Methane	0	negligble	--
Carbon Dioxide	13.3	17.1	15.2
Nitrogen + Argon	0	negligble	--
Hydrogen/Carbon Monxide Ratio	0.65	0.80	0.72

3.1-2 Notes

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1. D. M. Todd, “Gas Turbine Improvements Enhance IGCC Viability”, 2000 Gasification Technologies Conference, San Francisco, CA, October, 2000.

BIOGRAPHY

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Dr. Vincent G. McDonell is the Associate Director of the UCI Combustion Laboratory and is an adjunct Associate Professor at the University of California, Irvine. Dr. McDonell's research focuses on gas turbine combustion systems and components including the design and characterization of devices for both liquid and gas fired applications. Research contributions range from micro-turbine generators, to central plant gas turbines, to propulsion gas turbines. Fuels experience ranges from natural gas to hydrogen to coal derived fuel gas and liquids. He has extensive experience in application of laser based and conventional diagnostics to a wide array of combustion devices and has particular expertise in the physics of two-phase transport and optical diagnostics for two-phase flows including phase Doppler interferometry. He also regularly applies CFD in the analysis and design of combustion systems and components. Dr. McDonell is a member of the Combustion Institute, ILASS-Americas, AIAA, and ASME. He currently serves on the executive committee of ILASS-Americas and the Western States Section of the Combustion Institute and also serves on the Academic Advisory Board the University Turbine Systems Research program. Research by Dr. McDonell has been documented in over 40 publications.