Syngas Upgrading Flexibility Using Hot Oxygen Technology

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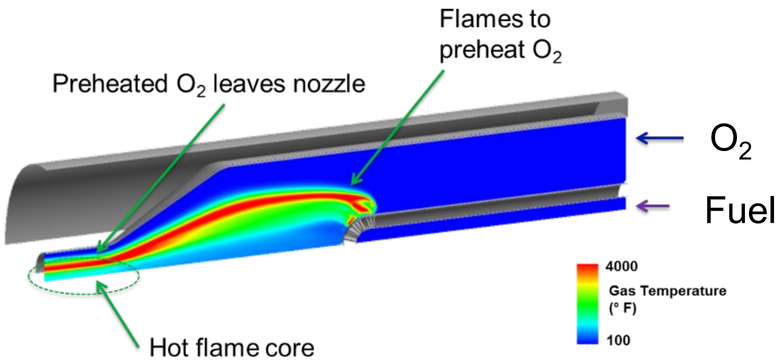
Making our world more productive

Hot Oxygen Technology

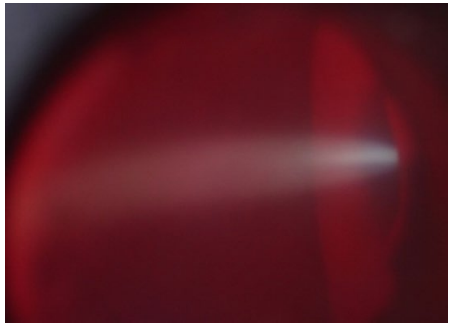
- Internal oxy fired flame
- Excess oxygen reacts with fuel
- Residual O2 and combustion products are very hot and highly reactive
  - 60-95% O2, 2000-4500°F
- Accelerate mixture through a nozzle
  - High velocity / momentum through exit nozzle → Excellent mixing

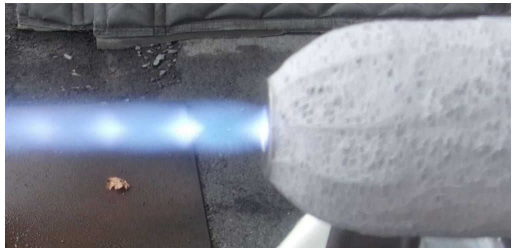
Major Strength: Reactive Mixing

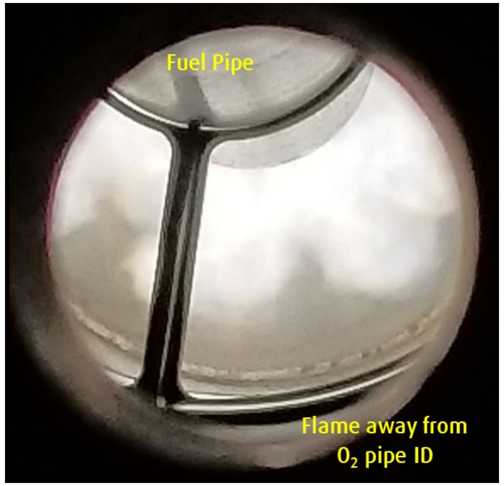
- **Hot Oxygen is a Platform Technology**
  - Refineries, Cement Kilns, Chemicals
  - Gases, Liquids, Sludges, Particulates



O_2 preheated by highly fuel lean combustion upstream of nozzle

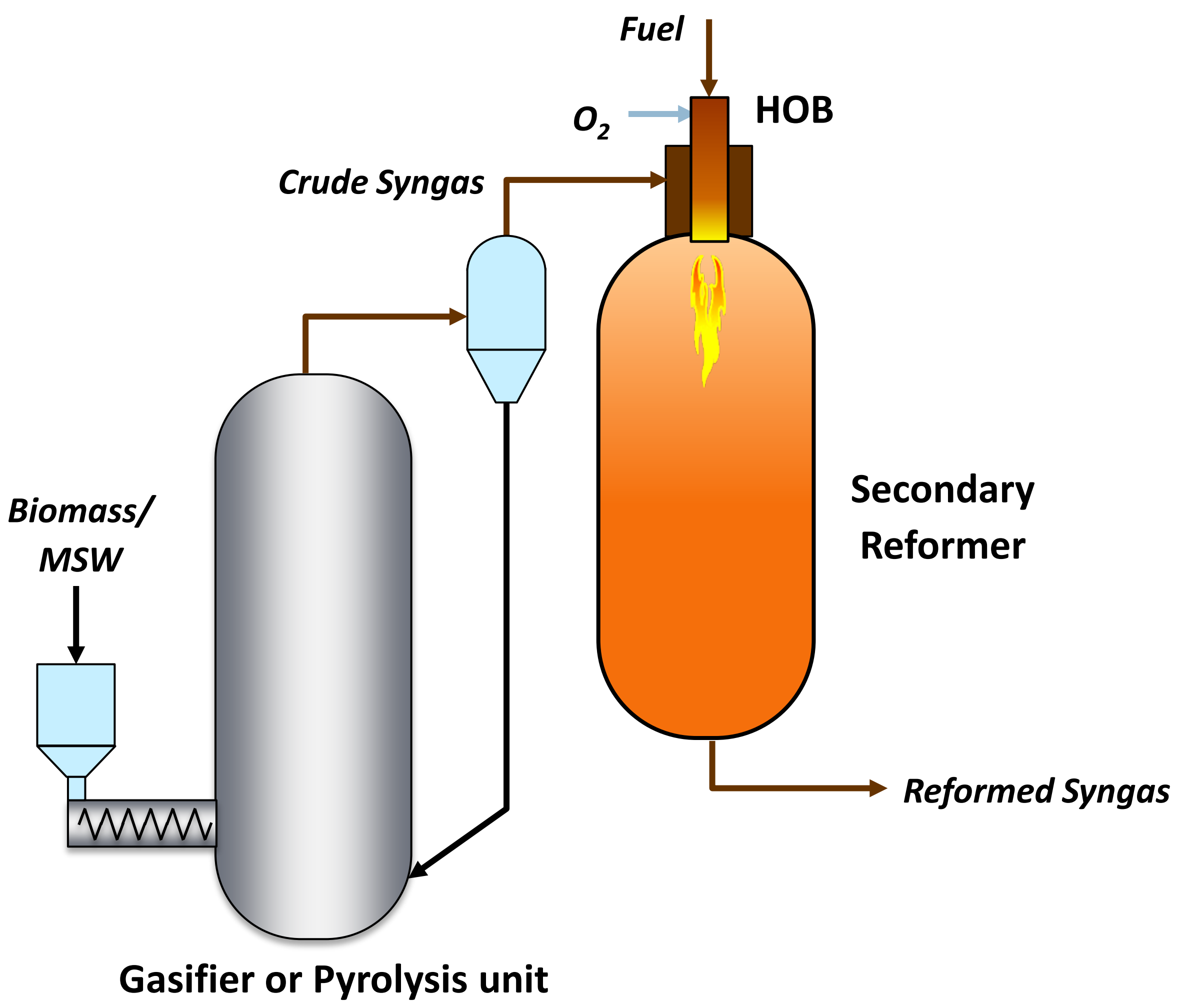






View upstream of nozzle - from the back

HOT in a Secondary Reformer



Hot Oxygen in Secondary Reformer can:

- Reform hydrocarbons and tars in syngas streams to H_2 and CO
- Adapt to changing feedstocks on the fly without any hardware changes
- Reduce reactor and / or burner complexity while ensuring excellent mixing → no tar slip and low HC slip
- Minimize soot formation
- Excellent scalability – especially down scaling to small systems
- Adjustments in H2:CO ratio possible – depends on initial feedstock and availability of steam or CO2
- Generate syngas from direct sources (eg natural gas)
- HOB Fuel can be any available fuel gas with > 200 BTU/scf

Pilot Scale HOT Development

Species	Range in feed (vol%)		
CO	3.7%	-	10.4%
CO_2	0.7%	-	2.7%
H_2	54.3%	-	67.0%
N_2	1.0%	-	4.2%
CH_4	21.2%	-	29.7%
C_7H_8	0.0%	-	1.9%

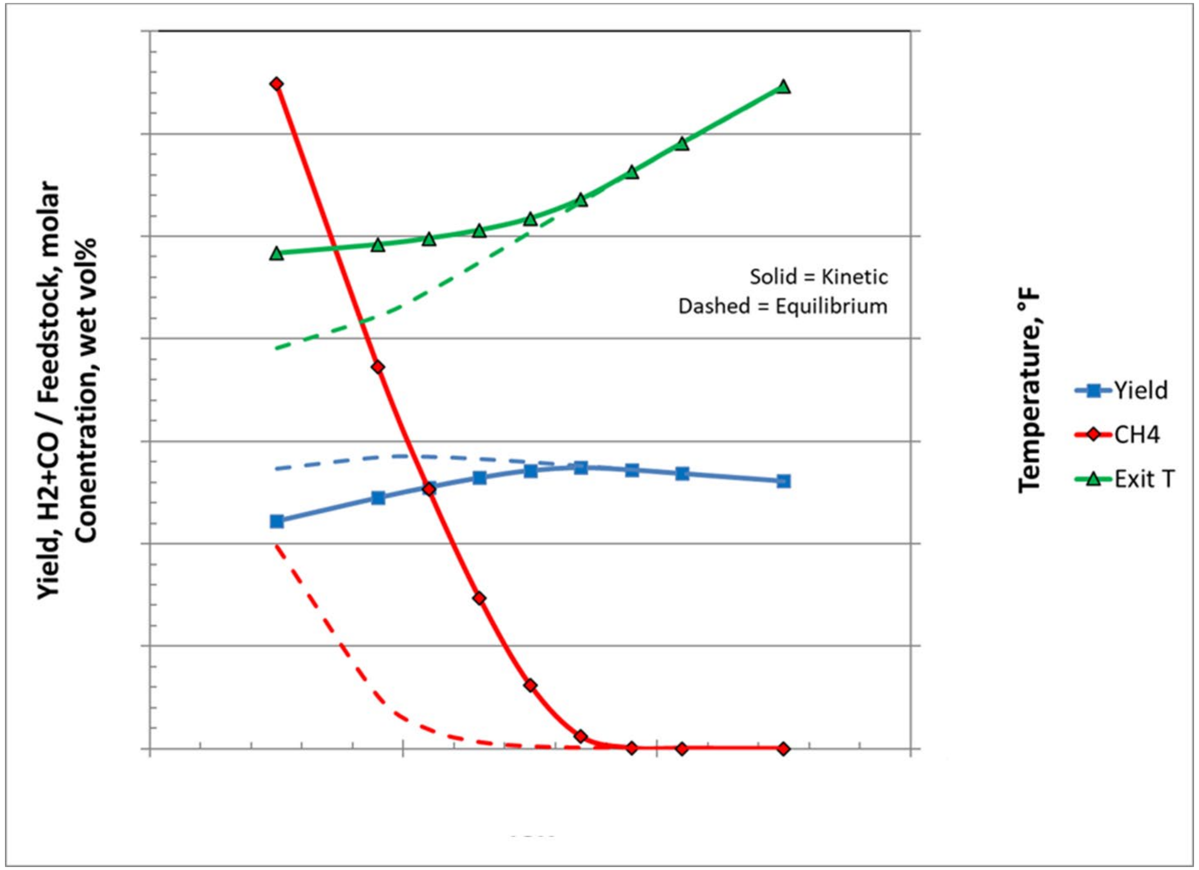
1 MMSCFD syngas, 75 psig

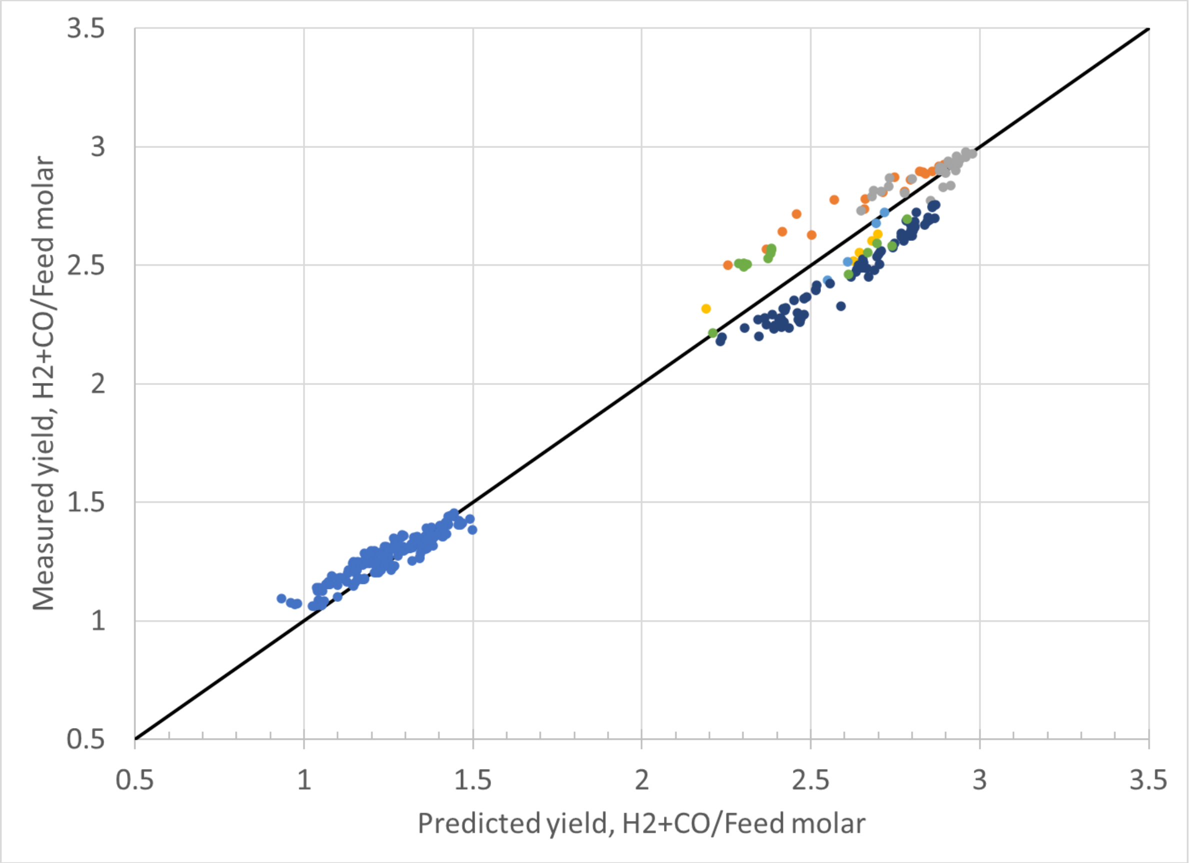
Species	Range in feed (vol%)		
CH_4	49.1%	-	97.4%
C_2H_6	1.1%	-	2.4%
C_3H_8	0.0%	-	0.1%
N_2	0.1%	-	0.3%
CO_2	0.0%	-	21.8%
H_2O	0.0%	-	49.6%

2 MMSCFD syngas, 35 psig

Investigated: hydrocarbon conversion, O2 use requirements, H2:CO ratio adjustments (including steam and CO2 injection), soot formation, N chemistry, feedstock injection method and tar conversion – all as a function of pressure, operating temperature, residence time

HOT Performance Model





- Performance model based on detailed chemical kinetics and mixing correlations (not CFD)
- Model accounts for kinetically limited reforming reactions at low temperatures and residence times better than equilibrium based approaches

HOT Handles POx Feedstock Variability and Enables Alternate Feeds

- Feedstock can vary
  - Normally with natural variation within a given feedstock type
  - Changing feedstock type altogether
- Mixing between crude syngas and oxidant driven entirely by HOB, so reactions are always under control
- Enables feedstock flexibility to adapt to changing technical and economic drivers

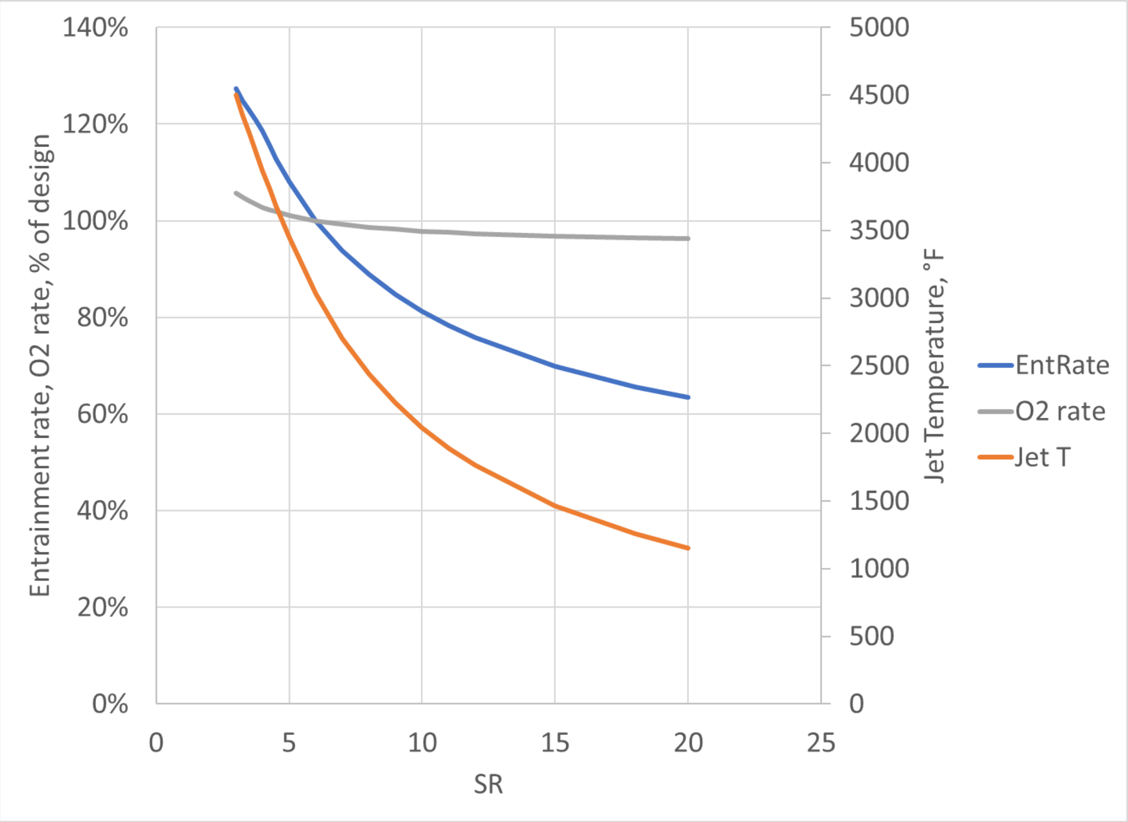
Feed type		Imaginary biomass syngas	50% syngas + NG		NG	NG + 25% CO2
Feedstock Input	lbmol/hr	1000	665	800	288	366
HOB O2	lbmol/hr	229	229	322	229	229
HOB Fuel (NG)	lbmol/hr	38	38	54	38	38
Syngas Output	lbmol/hr	1581	1332	1770	975	1016
	°F	2536	2560	2555	2582	2731
H2+CO	lbmol/hr	1002	984	1371	829	764
H2:CO		1.2	1.4	1.5	1.7	1.2
residence time	sec	2.0	2.7	2.8	3.2	3.3

With HOB as the driving force, feedstocks with widely varying properties can be handled without changing the POx burner

HOT Operational Flexibility

- Operators have control over the jet properties by varying the HOB stoichiometric ratio (SR)
  - SR = actual O2 provided / O2 for ideal combustion
  - Lower SR gives higher temperature, higher velocity jets
  - Higher SR gives lower temperature, lower velocity jets

- Enables on the fly adjustments to counter process changes
  - For example, increasing the crude syngas temperature will decrease the entrainment rate of syngas into the jet
  - Decreasing the HOB SR can restore the entrainment rate, avoiding potential issues such as increased soot formation or hydrocarbon slip

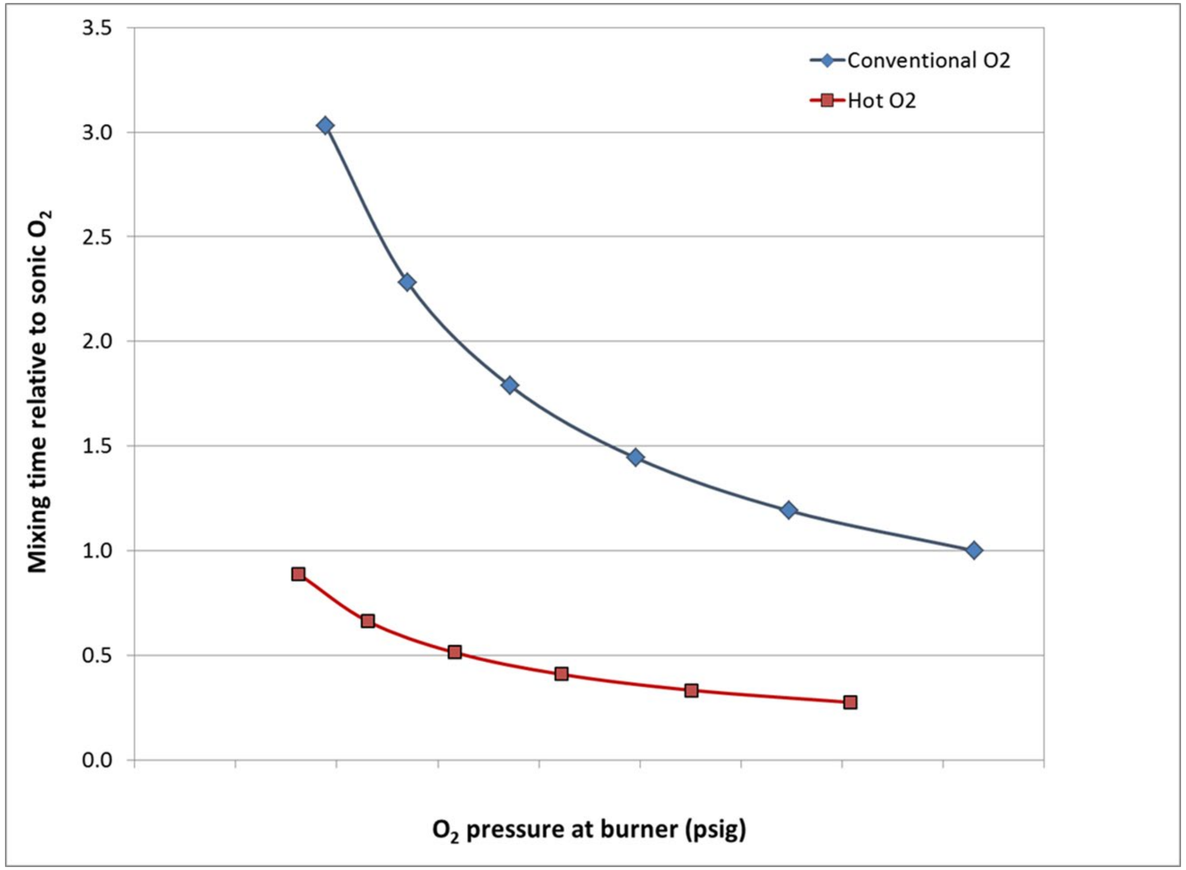


HOT systems can be continuously optimized based on current operational circumstances, keeping the plant running longer

HOT Turndown Capability

- Due to high temperature, hot oxygen jets can be accelerated to very high velocity before reaching sonic velocity
  - Momentum drives mixing between jet and surrounding gases
  - Even at low operating rates, a hot oxygen jet will outperform a conventional “cold” O2 jet at high operating rate

- At turndown, the momentum ratio of hot oxygen to feedstock remains strong, allowing very low operational turndown
  - At least 50% turndown, more depending on specific circumstances



Hot Oxygen Technology provides a wide operating range

Summary

- Excellent performance in converting hydrocarbons and tars, Hot Oxygen Technology
- Tolerates large variation in feedstock properties
  - Seamless response to natural variation in biomass feeds
  - Enables plants to also respond to market opportunities as feed prices vary
- On the fly adjustments to respond to operation conditions, keeping the plant running longer
- Wide operating range, down to 50% or more

- Hot Oxygen Technology is being deployed commercially as a syngas tar and hydrocarbon reforming technology