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CampusEnergy2022

Feb. 15-18 | Westin Boston Seaport District Hotel | Boston, Mass.

INTERNATIONAL DISTRICT ENERGY ASSOCIATION

Hydrogen Firing Burner & Boiler Impact

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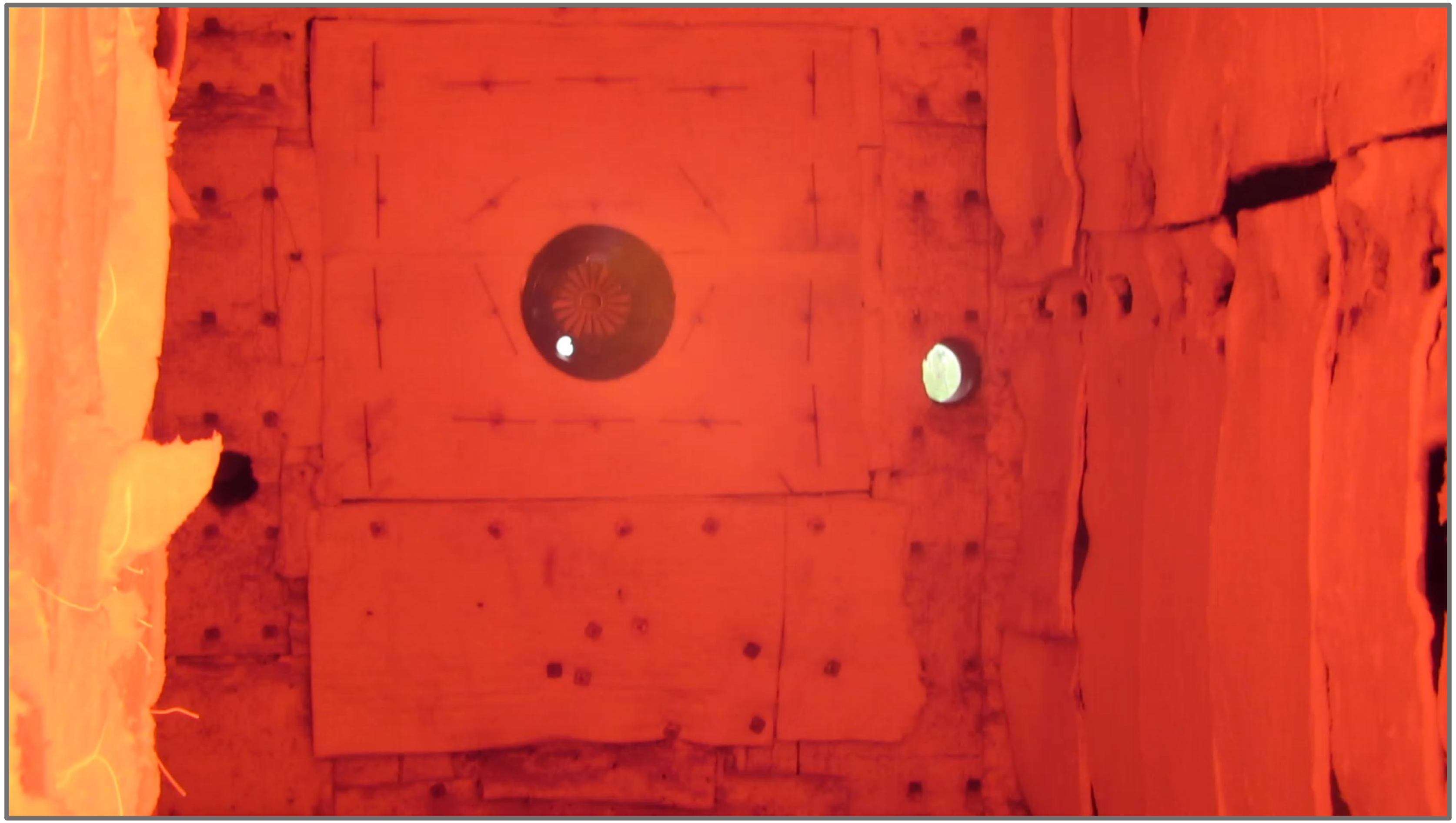
Presentation Overview

- Hydrogen vs. Natural Gas
- Burner Design
- Materials Selections
- Air Requirements and Fans
- Fuel Skids
- Controls
- Summary

Burner Design Considerations

- **Hydrogen Firing Characteristics vs. Natural Gas Firing Characteristics**
  - **Flame Speed**
    - H_2: 5.7 ft/s
    - Natural Gas: 1.3 ft/s
  - **Flame Temperature**
    - H_2 Adiabatic Flame Temperature: 3960 °F
    - Natural Gas Adiabatic Flame Temperature: 3518 °F
  - **Visibility**
    - A hydrogen flame is almost 100% translucent
    - Natural gas flames are more visible
- Radiant vs. convective surface impacts

Video of an H_2 Flame in a Test Furnace



Burner Design Considerations

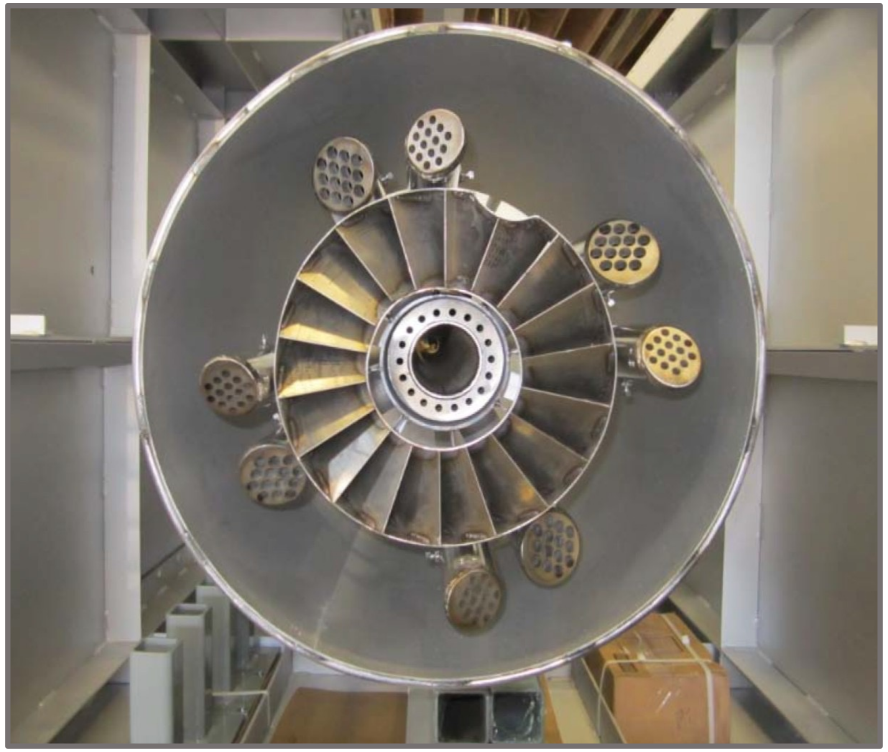
- **Burner Material Design Considerations - Metal Selection**
  - Elevated firing temperatures will require the burner’s nozzles and flame stabilizers to be upgraded to higher grade stainless or high temp alloy
  - Hydrogen Embrittlement and High-Temperature Hydrogen Attack requires the steel used in the burners to be chosen carefully

Burner Design Considerations

- **Burner Material Design Considerations - Refractory Selection**
    - Elevated firing temperatures and faster flame propagation speed subjects the burner throat and refractory to elevated temperatures
    - Refractory must be chosen carefully to prevent rapid deterioration of the throat
- **The flame speed and temperature must be balanced against the individual application.**

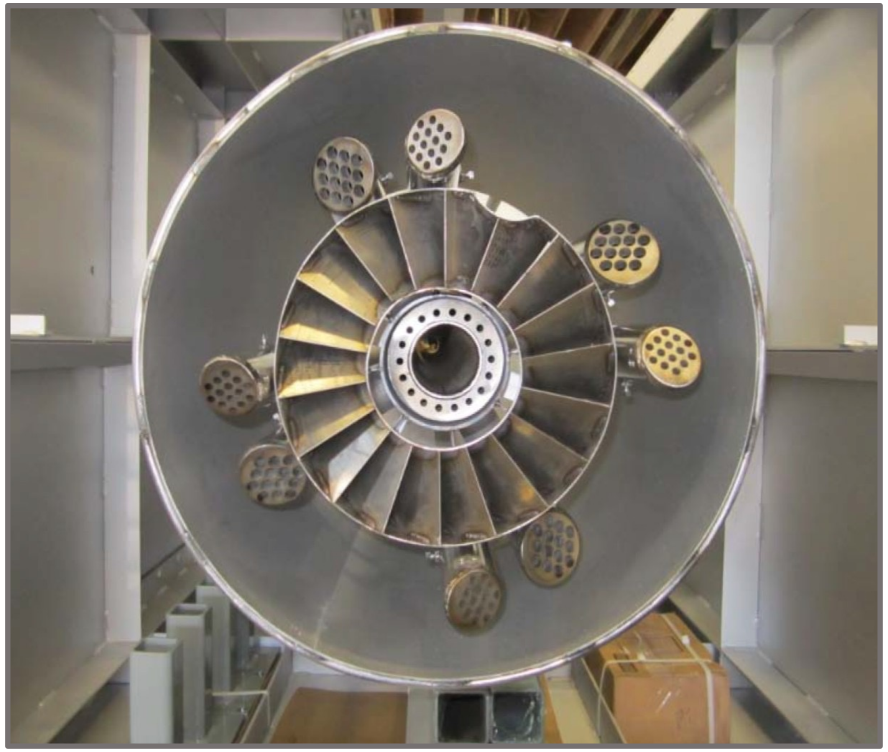
Burner Design Considerations

- **Lean Premix, Premix, or Rapid-Premix Burner Designs**
  - Not suited for elevated levels of H_2 in the fuel stream
  - Flame propagation speed increases as the content of H_2 increases in the fuel stream
  - Flashback occurs when **<u>fuel gas velocity exiting the burner nozzle is slower than the flame propagation speed</u>** in a premixed application (fuel and air are already combined)
    - Significant damage to the burner components can result rapidly
- **NOT RECOMMENDED**



Burner Design Considerations

- **Staged Combustion Burner Designs**
  - Fuel and air staging mechanisms are used to decrease NOx emissions without compromising the burner components
  - Both staging mechanisms work to **decrease peak flame temperature** thus decreasing NOx emissions
- **THE PREFERRED APPROACH**



Fan Design Considerations

- **The fan requirements for burning Natural Gas or Hydrogen are about the same**
  - Natural Gas requires **<u>723 lb air / MMBtu</u>** for stoichiometric combustion
  - H_2 requires **561 lb air / MMBtu** (~20% Δ)
  - However, to get the same NOx emissions as natural gas, H_2 requires ~15% more FGR
  - The additional mass flow from the FGR requires the fan to be sized about the same as with natural gas firing.

Fuel Skid Design Considerations

- **Skid Construction**
  - **Line Sizing**
    - Zeeco sizes a fuel train so that the velocity of the gas passing through the valve train does not exceed Mach 0.16.
    - A gas that exceeds **Mach 0.16** will generate pipeline noise that exceeds **85 dBa**.
    - Natural Gas has a limiting velocity of 232 ft/s
    - H_2 has a limiting velocity of 660 ft/s
  - **No threaded joints, other than process connections**

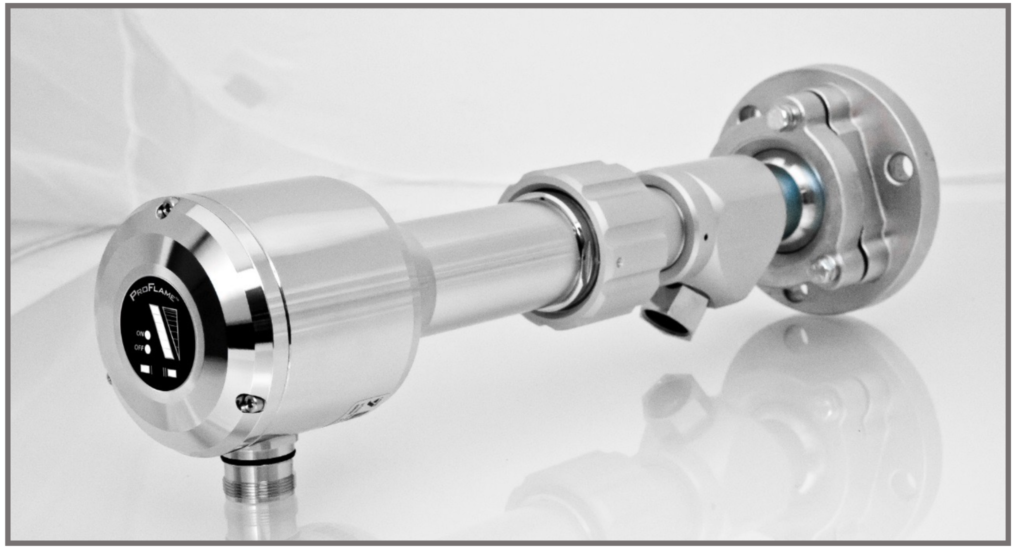
Fuel Skid Design Considerations

- **Skid Construction**
  - **Material Restrictions:**
    - Irons – Cast, Ductile, Malleable, and High Silicon (14.5%) are prohibited due to their lack of ductility and their sensitivity to thermal and mechanical shock
    - Valve and Piping materials must be carefully chosen to avoid failures from hydrogen embrittlement, which can lead to failure
  - **Valve Construction:**
    - Valves should be leak tested with helium. Helium leak tests of valves in the open position, leakage shall not exceed 1×10^{-8} ml/s when differential pressure between atmosphere and internal passages of the valves is greater than 100 kPa (14.6 psi)
    - Must adhere to valve standards listed in Table IP-8.1.1-1 in ASME B31.12-2019
    - **Valve CV*** must be sized appropriately to provide control resolution when firing Natural Gas and H_2 on the same burner

***CV** = Industry Valve flow co-efficient

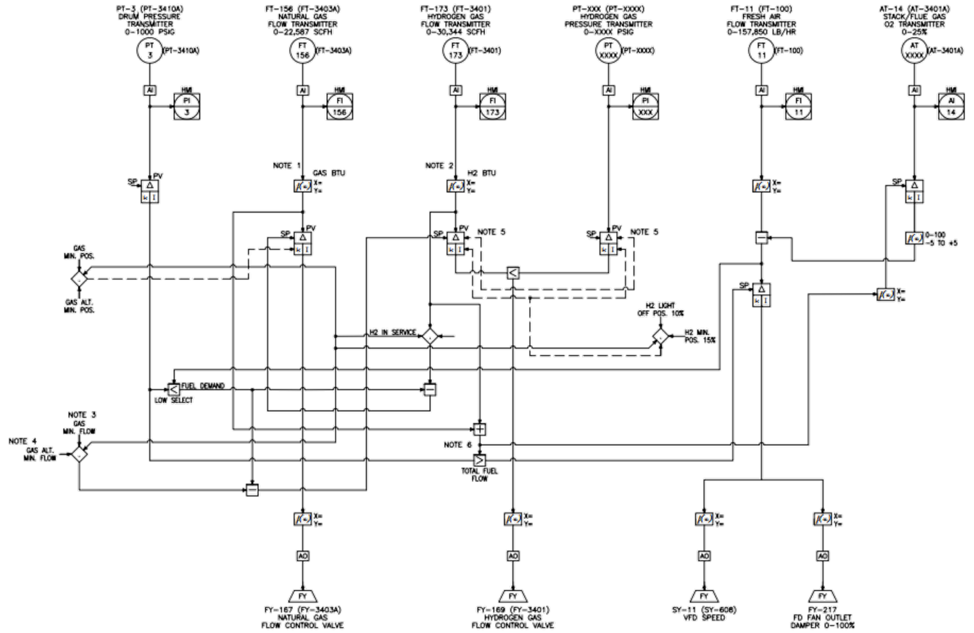
Instrumentation & Controls Considerations

- **Flame Scanners**
  - Proper scanner selection is critical
  - H_2 combustion generates water vapor. As the concentration of H_2 in the fuel approaches 80%, most flames scanners cannot consistently distinguish the flame with the high level of water vapor present
  - Modern solid state UV sensors can “see” through the water vapor produced in combustion (and steam atomization) and are reliable while older UV tube designs cannot



Instrumentation & Controls Considerations

- **Varying Fuel Stream**
  - Burners designed to fire a varying fuel composition will require:
    - Fully Metered Combustion Control System
      - Meters all fuel inputs to account for total combined gaseous heat input
    - Wobbe Index Meter or Specific Gravity Meter
      - Monitors the varying fuel streams' composition and provides the necessary input to the control system to adjust the fuel/air ratio based on real-time conditions
      - The inability to monitor the fuel stream composition and adjust the fuel/air ration accordingly can lead to an unsafe fuel rich condition



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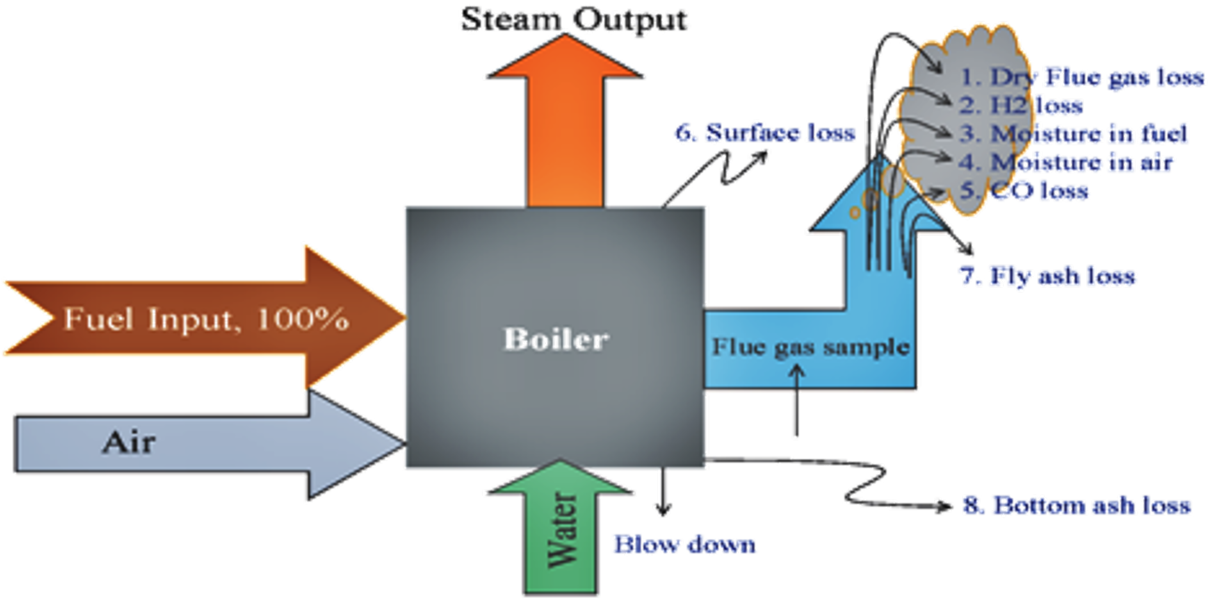
Boiler Design Considerations

- **ASME Power Test Code (ASME PTC 4.1-1964) is the governing standard for determining boiler efficiency**
  - The standard recognizes three main losses in boiler efficiency
    - Dry Flue Gas Loss
    - Loss Due To Moisture From
      The Combustion Of Hydrogen
    - Radiation And Convection Loss



Boiler Design Considerations

- **Loss Due to Moisture From the Combustion of Hydrogen**
  - When hydrogen is combusted it forms water vapor as a byproduct of combustion
  - The water vapor as it leaves the boiler takes with it the enthalpy at the temperature and pressure at which it leaves the boiler
  - For Natural Gas this loss is around 10.9%
  - For 100% H2 this loss is around 17%

$$CH_4 + 2(O_2 + 3.76N_2) = CO_2 + 2H_2O + 7.52N_2$$
$$2H_2 + (O_2 + 3.76N_2) = 2H_2O + 3.76N_2$$

Boiler Design Considerations

- **Governing Equation For Loss Due To Moisture From The Combustion Of Hydrogen**
  - $L_H, \% = \frac{900 * H_2 * (h_g - h_f)}{HHV}$
    - $L_H = Loss\ Due\ To\ Moisture\ From\ The\ Combustion\ Of\ H_2$
    - $H_2 = weight\ fraction\ of\ hydrogen\ in\ the\ fuel$
    - $h_g = enthalpy\ of\ water\ vapor\ in\ the\ flue\ gas$
    - $h_f = enthalpy\ of\ water\ in\ the\ combustion\ air$
    - $HHV = higher\ heating\ value\ of\ the\ fuel$

Boiler Design Considerations

- Case Study
  - Analysis of boiler efficiency when switching to a fuel stream with a large H_2 concentration
    - Boiler Fuel Streams
      - Fuel Stream A: 100% Natural Gas
      - Fuel Stream B: 85% H_2 / 15% Natural Gas
    - A - Natural Gas Firing Full Load Heat Input: 374 MMBTU/hr
    - B - Hydrogen Gas Firing Full Load Heat Input: 385 MMBTU/hr
  - **On average 3% more heat input is required with the combustion of hydrogen due to the loss of heat carried away by the excess moisture produced vs. NG combustion**

$$\frac{H_2 Heat\ Input}{NG\ Heat\ Input} = \frac{385\,\frac{MMBtu}{hr}}{374\,\frac{MMBtu}{hr}} = 1.03$$

Summary - Burning Hydrogen Fuels

- Burner Design Considerations
  - Metal & Refractory Choices
  - Burner Type
  - FD Fan Evaluation & Sizing
- Fuel Skid Design Considerations
  - Skid Sizing
  - Valve Sizing
  - Material Selection
- Instrumentation and Controls Considerations
  - Flame Scanners
  - Fully Metered
- Boiler Design Considerations
  - Efficiency Impact

Talk to Our Combustion Experts

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Questions?

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