A Comparison of Reheating Metals in Combustion Processes Using Natural Gas and Hydrogen Fuels

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Introduction:

As the world looks to decarbonize, industrial processes will have to meet the challenges. One possible outcome for industrial decarbonization is changing to hydrogen as a fuel source from traditional carbon-based fuels. However, pure hydrogen as an industrial fuel source in the metals industry is largely unknown, specifically from its metallurgical impacts and its heating characteristics. The use of hydrogen is hypothesized to have different metallurgical impacts depending on the material. This is of specific interest to materials such as titanium or aluminum which have an affinity for hydrogen. Also, the heating characteristics of hydrogen combustion for each metal is of interest and specifically the focus of the study presented.

Heat Transfer:

Heat transfer in the metals industry via combustion heat release is done primarily through radiation and convection. Radiative heat transfer will dominate at furnace temperatures over 1,100°F, as the radiative heat transfer fourth power of the temperature difference grows significantly above that threshold (see Figure 1). For steel applications, where temperatures usually range upwards of 2,000°F, radiation will be dominant and for heat treating aluminum, where temperatures are below 1,000°F, convective heat transfer will be the main mode of heat transfer. Due to change in heat transfer between metals, both most be studied when switching to a new fuel, such as hydrogen.

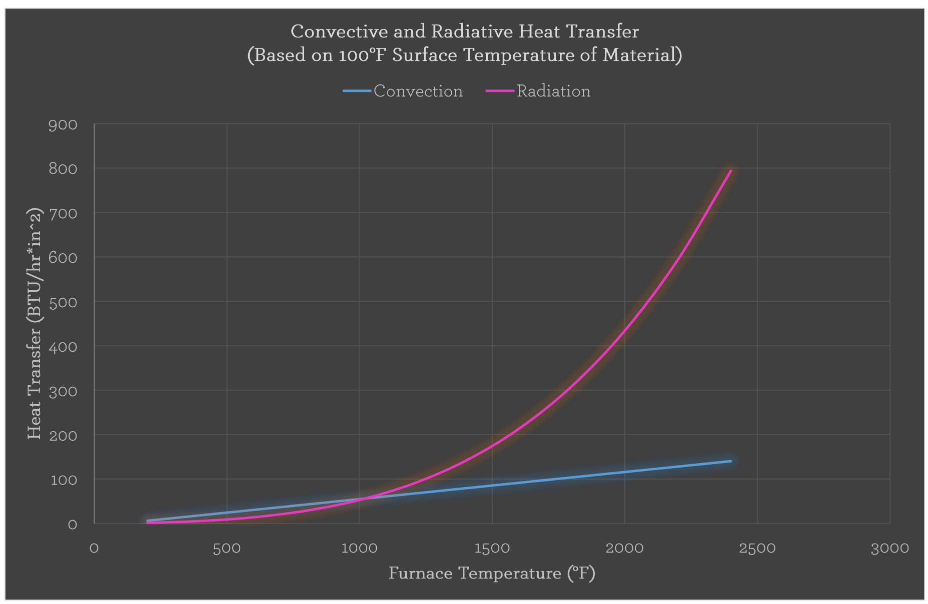

Figure 1 – Convective and Radiative Heat Transfer Comparison based on a 100°F Surface Temperature

Regarding radiation, the switch from natural gas to hydrogen will change the composition of flue gas in the furnace. In general, two factors affect the radiative heat transfer in an industrial furnace- the triatomic gas emissivity and the furnace temperature. The triatomic flue gas species in the furnace during natural gas combustion are water vapor (H_2O) and carbon dioxide (CO_2). With the transition to H_2

fuel, the carbon dioxide will be removed, leaving water vapor as the only triatomic molecule of substantial volume.

For the set of tests presented herein, it was decided to match the thermal input and air/fuel ratio between natural gas and hydrogen. Matching input and air/fuel ratio results in slightly lower air flow required for the burners. Subsequent tests will be carried out matching air velocity from the burners. For natural gas, at high fire, the combustion air, fuel and resulting flue gas flows are as follows.

Table 1 – Combustion Air, Fuel and Resulting Flue Gas flows for Natural Gas at High Fire

					Flue Gas			
Combustion Air Flow	Excess Air	Fuel Flow	Heat Input HHV	Heat Input LHV	CO_2	H_2O	O_2	N_2
scfh	*%*	*scfh*	*BTU/h*	*BTU/h*	*scfh*	*scfh*	*scfh*	*scfh*
15,000	10	1,365	1,441,670	1,301,477	1,451	2,805	285	11,869

For Hydrogen, using heat input based on lower heating value (LHV) as a constant, the combustion air, fuel and resulting flue gas flows are as follows.

Table 2 - Combustion Air, Fuel and Resulting Flue Gas flows for Hydrogen at High Fire

					Flue Gas			
Combustion Air Flow	Excess Air	Fuel Flow	Heat Input HHV	Heat Input LHV	CO_2	H_2O	O_2	N_2
scfh	*%*	*scfh*	*BTU/h*	*BTU/h*	*scfh*	*scfh*	*scfh*	*scfh*
12,468	10	4,738	1,538,303	1,301,477	-	4,738	237	9,865

For H_2, the approximate amount of triatomic molecules in the flue gas is slightly higher compared to natural gas.

While the total flows out of the burner vary between the two fuels, it is expected not to have a large impact on the convective heat transfer.

Laboratory Setup:

The tests are run in a box style furnace of dimensions 96.5” wide x 94.5” deep x 54” tall. A drawing of the furnace is shown in Figure 2.

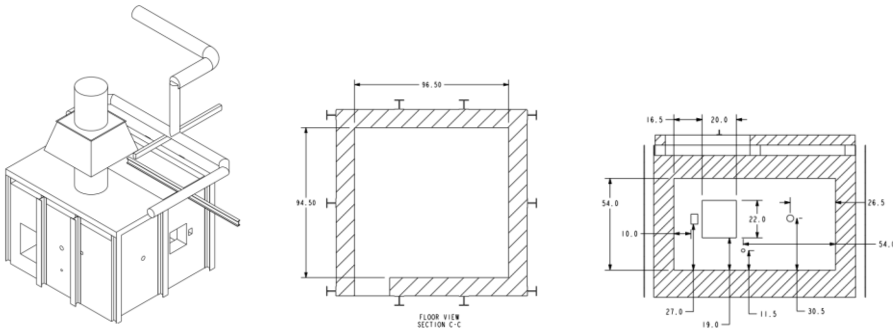

Figure 2 – Drawing of Test Furnace

The furnace is fired with two (2) high velocity burners mounted the side walls. The burners used are North American Tempest DMC burners, shown in **Error! Reference source not found.**. The combustion technology used for the burners and controls this test are the same as heat treat/forge installations in industry and therefore will mimic operation of typical furnaces.

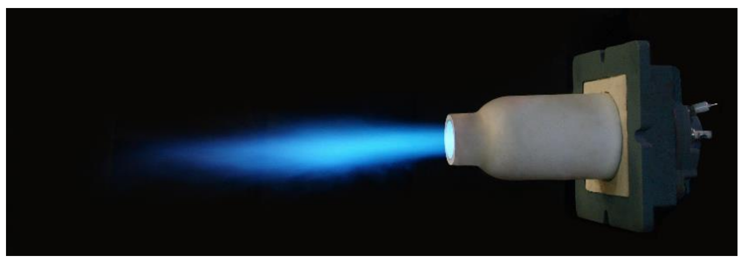

Figure 3 – Tempest firing on Natural Gas

Hydrogen Supply

Fives North American’s Combustion Laboratory is equipped with a hydrogen supply system. The supply is delivered by compressed gas on tube trailers. At maximum capacity, a maximum flow rate of approximately 62,000 scfh (1,700 Nm^3/h) is achievable. The facility is located on the rear of the property (shown in Figure 4), connected to the laboratory by 1000 ft of stainless steel pipe. It is connected to all furnaces in the laboratory to facilitate burner and process testing.

Figure 4 – Fives North American Hydrogen Infrastructure

Methodology:

Two separate test sets were completed for plain carbon steel. The samples were placed around the furnace, as shown in Figure 6, and instrumented with thermocouples. Each piece had two (2) thermocouples, one on the surface and one in the center. A table of the steel piece sizes is shown.

The initial conditions of the furnace were similar in each test. The furnace was run to a temperature of 2,250°F and soaked. The test was finished when the average temperature of all the pieces exceeded 2,150°F.

Table 3 – Test Piece Dimensions

Piece ID	Size of Piece	Piece Weight (lbs)
CY1	7.03"H x 4.03" Diameter	25.8
CY2	6.31"H x 4.02" Diameter	22.8
CY3	6.56"H x 4.02" Diameter	24.7
CY4	3.81"H x 4.01" Diameter	13.7
CY5	17.13"H x 4.0" Diameter	60.9
BK6	15.31"L x 6.63"H x 6.5"W	179.0
BK7	4.0"L x 6.25"H x 6.38"W	42.9

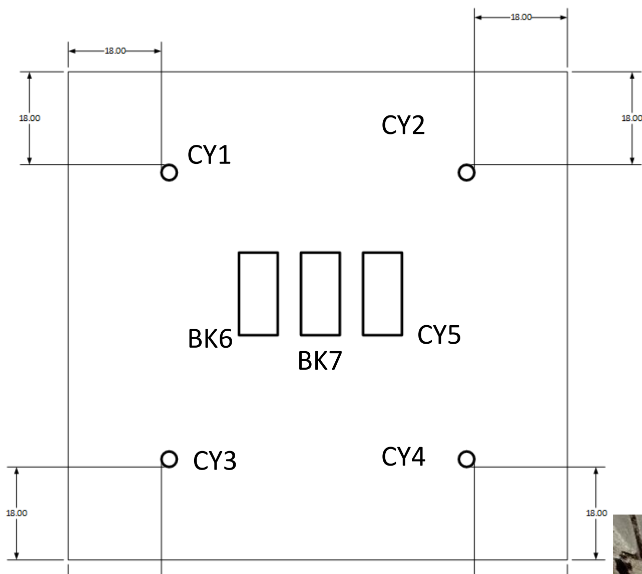

Figure 6 – Steel piece placement in Test Furnace


Figure 5 – Image of the pieces in the furnace

Results

The tests were run on the load on two separate days, with several days between tests to allow for sufficient cooling of the parts and furnace. This allowed for similar initial conditions for both tests.

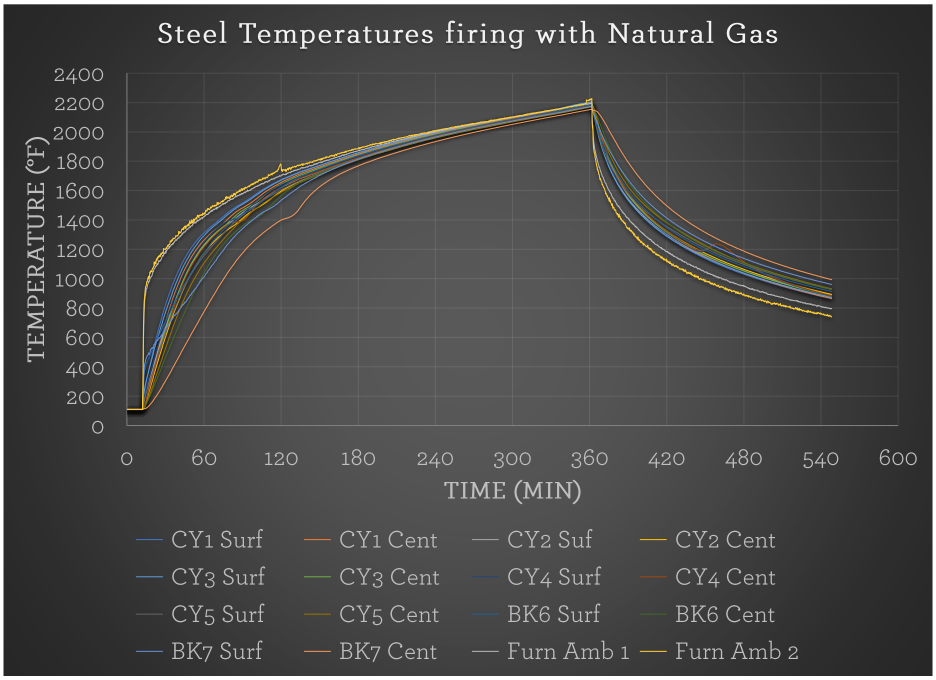

Figure 7 – Steel Temperatures as a function of time firing with Natural Gas

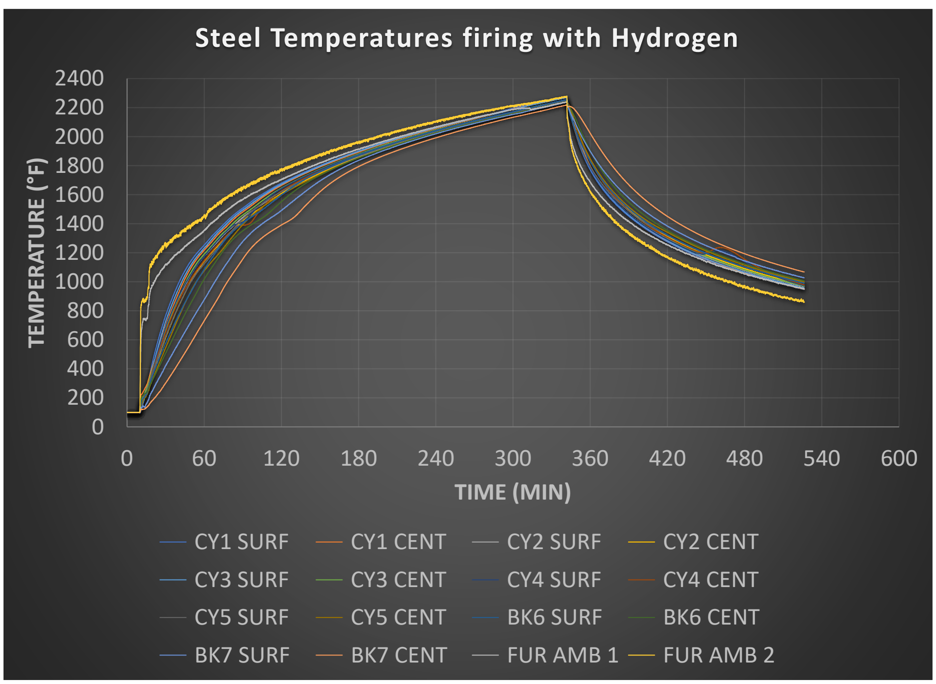

Figure 8 - Steel Temperatures as a function of time firing with Hydrogen

Discussion of Results

From the test results, it shows that the pieces have a similar heating rate on natural gas and hydrogen. If anything, the heating rate is slightly faster with using Hydrogen as a fuel versus natural gas. There is an increased amount of triatomic molecules firing with Hydrogen, which could lead to an increase in radiative heat transfer to the steel pieces. This coupled with increased flame temperature heats up the steel pieces at a faster rate. Looking at the steady part of the heat up curve after roughly 240 minutes on each test, the heat up rates are shown in the following table.

Table 4 – Temperature Increase during last 60 minutes of Test

Natural Gas		**Hydrogen**	
TC	F/min	TC	F/min
CY1 SURF	1.73	CY1 SURF	2.24
CY1 CENT	1.75	CY1 CENT	2.23
CY2 SURF	1.79	CY2 SURF	2.24
CY2 CENT	1.83	CY2 CENT	2.22
CY3 SURF	1.75	CY3 SURF	2.12
CY3 CENT	1.75	CY3 CENT	2.11
CY4 SURF	1.81	CY4 SURF	2.18
CY4 CENT	1.84	CY4 CENT	2.18
CY5 SURF	1.82	CY5 SURF	2.18
CY5 CENT	1.83	CY5 CENT	2.23
BK6 SURF	1.81	BK6 SURF	2.17
BK6 CENT	1.85	BK6 CENT	2.20
BK7 SURF	1.82	BK7 SURF	2.23
BK7 CENT	1.96	BK7 CENT	2.36

The table shows an increased heat up rate using hydrogen compared to natural gas.

Total fuel consumption for each case was also logged. Total fuel used in the hydrogen case was lower when compared to natural gas.

Test Run	**Total Fuel Usage (scfh)**	**Total Fuel Usage (MMBtu/h LHV)**
Natural Gas	14,777	14.1
Hydrogen	48,117	13.2

At the writing of this paper, it is realized that these several runs cannot lead to a definitive conclusion. However, the data trend is shows statistically relevant differences and merits further exploration.

Future Work

Further work will be focused on exploring the heat up rates on both steel and other metals such as aluminum to see if there is an effect similar to the results presented. Future tests will also look at the metallurgical impact of switching fuels to hydrogen and if increased hydrogen pickup is seen in the tested metals, with specific interest in aluminum and titanium.