Hydrogen: potential superfuel?

High hydrogen fuels have the potential to dramatically reduce CO_2 emissions compared to conventional fuels, depending on how the hydrogen is produced

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Hydrogen is a colourless, odorless, non-toxic, highly reactive, flammable, diatomic gas that is the most abundant element in the universe. The global demand for hydrogen is increasing rapidly.[1] Interest in hydrogen as a fuel continues to grow, mostly because it generates water when combusted, with little if any carbon dioxide (CO_2) generated, depending on how it is produced. **Figure 1** shows the more H_2 in the fuel, the less CO_2 produced.

In the past, using hydrogen as a fuel was only economical in certain applications. Reducing CO_2 emissions and concerns about fossil fuel depletion are two major recent drivers for considering high hydrogen fuels for more applications.[2]

Hydrogen has the potential to be an important fuel depending on how it is generated.[3] Today, large scale hydrogen production is by steam methane reforming (SMR). SMR furnaces generate CO_2 emissions. If those emissions are captured, this is referred to as 'blue hydrogen'. Oil and gas producers are particularly well positioned to produce blue hydrogen because natural gas is relatively low cost and because those producers have the infrastructure to produce hydrogen.[4] If the CO_2 is not captured, this is referred to as 'grey hydrogen'. Hydrogen made with renewable energy, such as wind or solar energy powering an electrolysis process, is referred to as 'green hydrogen'.

While there is increased interest in using hydrogen as a fuel, high levels of hydrogen have been used in some applications such as boilers and fired heaters for many years. For example, the off-gas from ethylene crackers using natural gas as the feedstock is 70-85% H_2 which is used as fuel for the cracking furnaces.

There are important issues to consider for new applications using high H_2 in the fuel. For example, hydrogen has a higher potential for leaking from fuel delivery systems, a very wide flammability range, a higher flame speed, a lower volumetric heating value, less air required per unit heating value, and a higher adiabatic flame temperature compared to other fuels. These issues impact the combustion system, which means it may not be a simple conversion from existing hydrocarbon fuels to high hydrogen fuels.

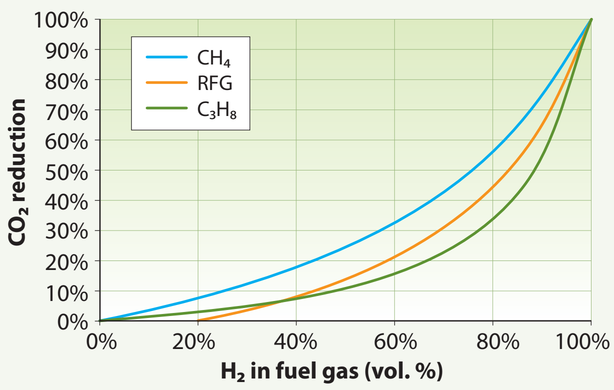

Figure 1 CO_2 reduction with hydrogen addition to various fuels (RFG = refinery fuel gas = 20% H_2, 55% CH_4, 10% C_2H_6, 10% C_3H_8, 5% C_4H_{10}). Assumes no CO_2 is produced making the hydrogen

Hydrogen combustion

Hydrogen is an element whose natural state at

Property	H_2	CH_4	C_3H_8
Molecular weight	2	16	44
LHV, MJ/Nm³	10.8	35.8	91.2
LHV, MJ/kg	119.8	50.0	46.3
Adiabatic flame temperature*, °C	2048	1878	1904
Max. flame speed, cm/s	325	44.8	46.4
Flammability limit, vol% air	4-74.2	5-15	2.1-9.5

* based on 10% excess air, air temperature: 20°C.

Table 1

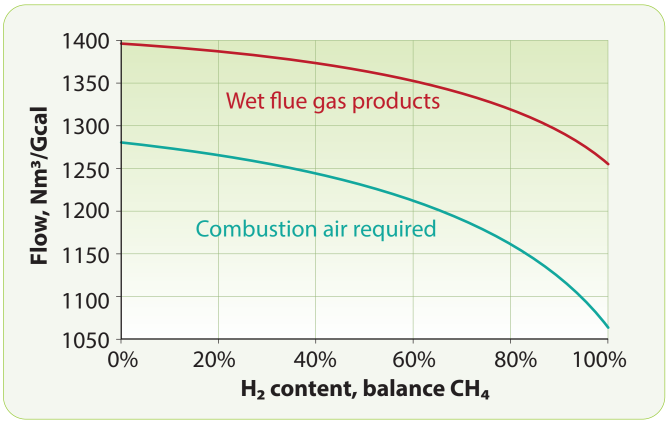

Figure 2 Combustion air required and wet flue gases produced for blends of H_2 in CH_4 (15% excess air assumed)

atmospheric temperature and pressure is H_2. In that state, it is a low density gas that can easily leak from piping systems.

Hydrogen has many unique properties compared to common hydrocarbon fuels (see **Table 1**). It has a very high heating value on a mass basis but a very low heating value on a volume basis because of its low density. Hydrogen's low volumetric heating value means much higher volumetric flow rates for a given heat input, compared to other common fuels. Higher volumetric flows mean higher fuel gas pressure.

Hydrogen has a higher flame speed and ignition temperature compared to many common fuels. It has a very low minimum ignition energy so it is easily ignited with a minimal spark. This is a good characteristic when ignition is desired but less desirable when trying to prevent ignition, as static electricity, for example, could easily ignite H_2. Hydrogen has a relatively high adiabatic flame temperature and wide flammability limits compared to other fuels. It also requires considerably less combustion air, per unit firing rate, and generates fewer combustion products (see **Figure 2**).

Potential advantages

An important potential advantage of using pure hydrogen as a fuel is the combustion products do not contain CO_2. However, if hydrogen is generated by conventional SMR, then CO_2 is a by-product of the production process. If hydrogen can be produced using renewable energy, it is possible to minimise or even eliminate CO_2 generation depending on the process. Another emissions benefit is the absence of carbon in the fuel, which means no soot (smoke), carbon monoxide, or unburned hydrocarbons.

In many applications, the limit on increasing an existing burner's firing rate is the combustion air capacity. While it is usually easy to get more fuel flow by increasing the size of the fuel injector holes, it may not be very easy to significantly increase the combustion air capacity. Since hydrogen requires less combustion air (see **Figure 2**), it may be possible to increase a burner's firing capacity less expensively using hydrogen than by alternative methods such as increasing the combustion air fan capacity.

Potential challenges

There are many potential challenges of using high hydrogen fuels. Hydrogen has a considerably higher flame speed, which makes it much more susceptible to flashback in a premix burner. This means the turndown (ratio of highest to lowest firing rate) in premix burners may be significantly reduced with high hydrogen fuels. Hydrogen embrittlement is another fuel delivery system concern, which can be handled with using appropriate materials selections. Noise could increase due to higher exit velocities for high hydrogen fuels. However, noise can usually be mitigated with proper fuel injector design and muffler selection. The higher adiabatic flame temperature may increase thermal NOx. This can be mitigated by increased furnace gas recirculation, a well-known NOx reduction technique, which is possible because of hydrogen's wider flammability limits.

Design considerations

Valve packings and seals need to be considered because of the higher likelihood of leakage. Welding piping joints may be preferred to minimise leaks. Since hydrogen embrittlement is a problem with carbon steel, stainless steel piping should be used.

A more conventional fuel like natural gas may be used at startup before switching to hydrogen. This typically occurs when hydrogen is produced by SMR. Burners designed to fire on hydrogen start up initially on natural gas until the SMR process is established and hydrogen is being produced (see **Figure 3**). This means burners may need to be capable of firing on both natural gas and high hydrogen fuels. Since the combustion characteristics between hydrogen and other fuels can be significantly different, this could complicate

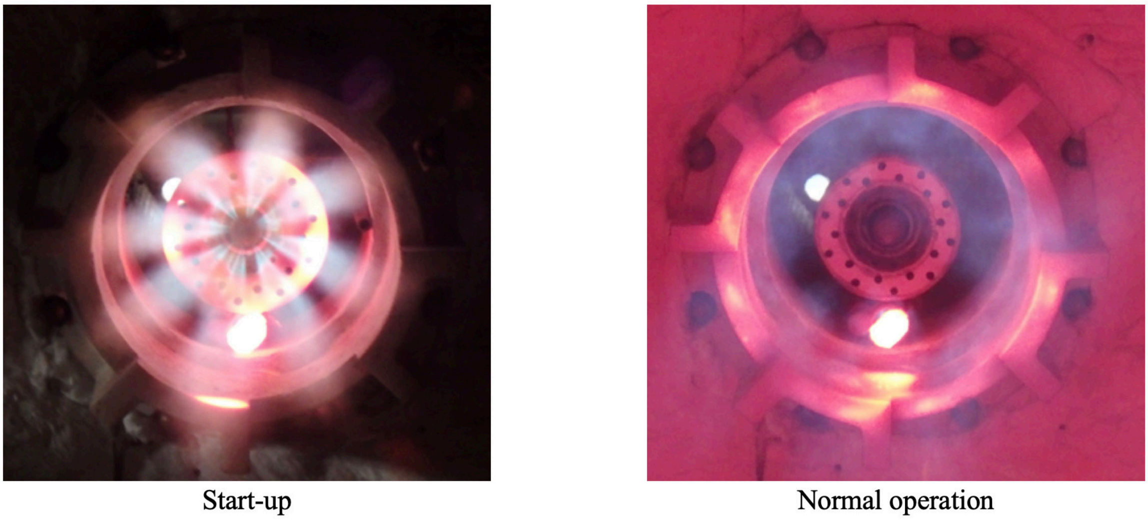

Figure 3 Left: burner starting up on natural gas with base fuel injectors. Right: normal operation on high H_2 fuel gas with added staged fuel injectors

burner design and operation. This is handled through proper burner design.

Hydrogen produces a weaker flame rectification signal in flame rods commonly used in pilots. Also, higher flame temperatures with hydrogen may shorten a flame rod's life. Conversely, hydrogen produces a very strong ultraviolet signal easily detected by ultraviolet flame scanners. The benefit is that flame sighting of UV scanners is less challenging and hydrogen flames may be able to be seen through more dust on a scanner lens before needing to be cleaned compared to conventional fuels. Flame scanners can be mounted on pilots to replace flame rods.

Fuel injectors may need to be changed if retrofitting existing burners designed for another fuel like natural gas. Fuel injection holes (ports) may need to be significantly larger when using high hydrogen fuels, to reduce the fuel pressure when using hydrogen. Larger holes reduce the likelihood of tip plugging. The actual impact on retrofitting existing burners is very dependent on the burner design. For example, previous experience with boiler burners has shown that traditional staged combustion technology may be compatible with switching to hydrogen, but vibration could be an issue if the burners are not properly designed. Because of hydrogen's shorter flames, overheating the burner front could be an issue. Therefore, burner parts may need to be made of high grade stainless steel.

Radiation heat transfer is another factor to consider. The flame temperature is likely to increase significantly, assuming everything else is approximately constant. Since radiation is dependent on the fourth power of the absolute temperature, radiation would be increased. Also, gaseous radiation may be increased due to the higher water content in the flue gases. However, since there is no carbon in hydrogen, there would be no soot formation. That means a hydrogen flame would not have any soot (luminous) radiation, which can be significant for hydrocarbon fuels. Some studies have shown a relatively minimal impact on heat flux when switching from hydrocarbon fuels to hydrogen.[5]

Conclusions

Using high hydrogen fuels has the potential to dramatically reduce or eliminate CO_2 emissions compared to conventional hydrocarbon fuels, depending on how the hydrogen is produced. Hydrogen has many unique characteristics, such as a higher flame speed and adiabatic flame temperature, compared to conventional fuels. There are many challenges and design issues that need to be considered when using high hydrogen fuels. In general, depending on the specific application, the transition from typical hydrocarbon fuels to hydrogen may be possible with relatively little change in performance. A thorough analysis is recommended before making such a change.

VIEW REFERENCES

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