Green steel galvanizing

In the future, there will be a growing demand for green steel produced using renewable energy. This demand will impact both crude steel production and downstream processes, such as heat treatment. There are several options for heating a galvanizing line using renewable energy:

- *Electrical heating via resistance, or induction heating*
- *Bio-methane*
- *Renewable hydrogen*
- *Renewable ammonia, or other green fuels*

All of these options have their challenges, especially in view of the transition towards renewable energy. Hybrid solutions allow for switching between energy carriers, depending on availability and price.

Author: Joachim G. Wuenning
WS Wärmeprozesstechnik GmbH

INTRODUCTION

Many people view climate change as one of the biggest threats to mankind. Technical, but also social efforts will be required to meet the goals, formulated in the 'Paris Climate Agreement', to limit global warming to less than 2°C and preferably less than 1.5°C. Combustion of fossil fuels is by far the largest human contribution to global warming. Fossil fired power plants and internal combustion engines are already in the public focus. The transformation to alternative vehicle propulsion technology has just started and the days of coal fired power plants are numbered.

Combustion of fossil fuels for the generation of heat for industrial furnaces is also a large contributor to greenhouse gases and air pollution. The industrial heating sector is not yet in the public focus, but that will soon change and therefore the topic should be addressed proactively. For the mid- to long-term, heating in industrial processes is likely to rely on renewable electricity, non-fossil fuels, or a combination of both. Humans used non-fossil fuels for hundreds of thousands of years and will return to that habit after a short period of about 250 years where fossil fuels were used.

REDUCING CO_2 NOW AND IN THE FUTURE

Heating a furnace using electricity is locally CO_2 free, but CO_2 may be emitted at power plants since the majority of electricity is generated by burning fossil fuels. For every kilowatt hour produced, roughly 0.45kg of CO_2 is emitted to the atmosphere **[1]**. This value is valid for Germany's electric power mix and is similar in many other countries.

Heating an industrial furnace with a typical furnace temperature of around 1,000°C with natural gas produces about 0.4kg CO_2/kWh of available heat for a cold air burner and less than 0.25kg CO_2/kWh when using a recuperative or regenerative burner, where waste heat is recovered using a heat exchanger. That means, with today's electricity generation in most parts of the world, a state-of-the-art gas fired furnace emits much less CO_2 than an electric heated furnace.

So what are the options if you want to invest in a new furnace today? You can:

- Disregard the future production of green steel
- Build an all-electric furnace and hope that cheap regenerative electricity will be available in the near future
- Install a hybrid electric/fuel heating system
- Install an efficient fuel flexible gas fired system which can handle different fuels

ALL ELECTRIC FURNACES

You can debate if it is even possible to build an all-electric galvanizing line, but the options would be electric induction heating, or an electric resistance heated furnace, or a combination of both. If you are not located next to a large hydro-power facility, it is unlikely you have a constant supply of cheap renewable electricity. This will be true also in the near- to mid-term future, since the main sources of renewable electricity, wind and solar, are fluctuating and cause the electricity price to do the same. Galvanizing lines are usually operated 24/7 and therefore it is not an option to pause production at times of high electricity prices. This could be an option for batch processes but the idea that your production planning depends on the weather forecast would sound strange to most people.

HYBRID HEATING

If fuel and electricity prices are fluctuating, it is worth looking at the installation of a hybrid heating system.

Figure 1 shows a prototype of a hybrid electric radiant tube which can be operated as a gas fired radiant tube, or heat can be generated by the electric resistance heating elements inside the radiant tube. The inner tubes guide the combustion products and act as a support structure for the electrical heating wires. So far, the system has been tested in a single ended radiant tube and a future project will examine if W- or double P-tubes could be converted to gas/electric hybrid heating systems. Existing furnaces could be retrofitted in this way where long periods of cheap electricity prices justify the investment. At the moment it is hard to predict if, or when that will be the case.

Figure 2 shows an alternative approach to integrate electrical energy into a galvanizing line using 'fuel flexible' gas burners. Here a system can be designed using single-ended, or double-P tubes in combination with fuel flexible burners. For the next couple of years, this system could be used like a conventional natural gas fired system. The system could also tolerate future fluctuating gas compositions. If there is an abundance of cheap electricity in the future, an onsite electrolyser could be added to the plant, producing hydrogen to replace gas coming from the grid. The big advantage of this solution is the flexibility to use natural gas, green pipeline gas or electricity without modifying the equipment other than adding electrolysers when the time is right to justify the investment. A further option would be to use green ammonia which is cracked onsite to a hydrogen/nitrogen mixture **[2]**.

FUEL FLEXIBLE BURNERS

Today, most industrialized countries have a natural gas distribution grid, with customers accustomed to a constant gas quality with only little changes in composition. This might change in the future when gas from different sources is blended in the distribution grid. Most industrial gas burners can handle reasonable changes in gas composition quite well. The most relevant characteristic for the interchangeability of fuel gases is the Wobbe Index, W, shown in *Equation 1* as function of the heating value, H, the density of the fuel gas, ρ, and the density of dry air, ρ0.

$$W = \frac{H}{\sqrt{\frac{\rho}{\rho_0}}}$$

Eq 1 *Wobbe index*

Fuel gases with the same temperature, pressure and the same Wobbe Index provide the same energy output from a burner. If the Wobbe Index changes, the flow must be corrected by changing the fuel gas pressure, or using a flow throttle device to keep the burner power constant. If ▷

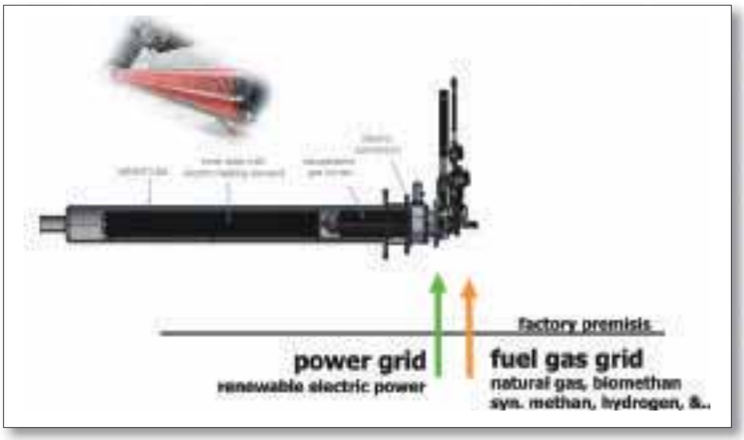

Fig 1 **Electric/gas hybrid radiant tube**

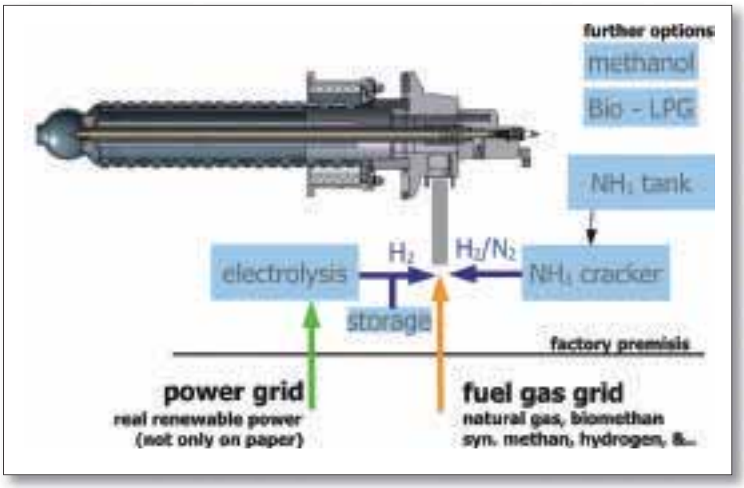

Fig 2 **Fuel flexible hybrid radiant tube**

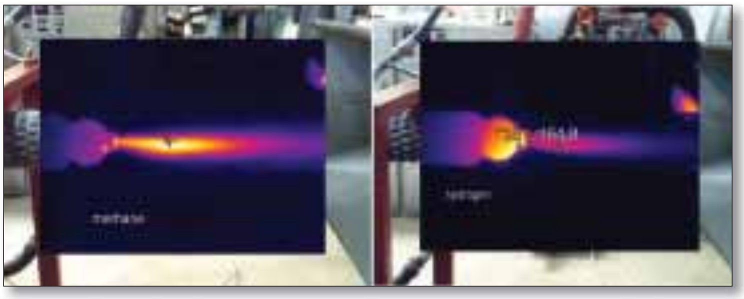

Fig 3 **Thermal image of a burner fired with natural gas and hydrogen**

Gas Properties	Natural Gas	Hydrogen
Calorific value /MJ/m³	36.1	10.8
Density /kg/m³	0.74	0.09
Air requirement m³/m³	9.6	2.4
Lower Wobbe index /MJ/m³	47.9	40.9
Specific air requirement /m³/MJ	0.27	0.2

Table 1 **Fuel properties**

Fig 4 **H_2-ready regenerative burner**

hydrogen is used as a fuel about 15% less air is required (*Table 1*). If hydrogen were to be added to natural gas and the fuel gas flow corrected, but the air flow is left unchanged, the system would be operating with somewhat excess air, slightly less efficiently, but it would be safe. If gas fluctuations were to occur in the future, adjusting the burners to increase the air rate would be an easy measure to ensure safe operation. With an effective heat recovery system and low exhaust gas temperatures, efficiency losses would be minimal.

FUEL GASES WITH A HIGH HYDROGEN CONTENT, OR PURE HYDROGEN

The flame speed of hydrogen is much faster than for hydrocarbons. This can cause some problems, especially in premixed burners where a flashback can occur, but also diffusion burners can show faster thermal deterioration. Another challenge resulting from faster combustion could be a higher flame peak temperature leading to higher thermal NOx emissions. Modern low NOx methods are available to address this problem. *Figure 3* shows thermal images of an open fired burner in flame mode using natural gas and hydrogen. When burning hydrogen, the high flame speed results in a flame closer to the burner tip causing higher temperatures of the burner. When switching to flameless oxidation, the fuel/air reaction is delayed and controlled by mixing of fuel, air and the exhaust and for some designs is independent from the flame speed of the fuel. Flameless oxidation, FLOX®, can provide very low NOx emissions and cooler burner tips for both, natural gas, hydrogen and any mixtures of both **[3]**.

A positive effect of hydrogen can be more reliable and easier ignition of burner systems. Many industrial burner systems can be operated with a high percentage of hydrogen, or with pure hydrogen, with little, or reasonable modification. Regenerative (*Figure 4*) and recuperative burners have been successfully tested in combination with double-P-radiant tubes using natural gas, pure hydrogen and any mixture of both. The first industrial long-term field tests have started.

OUTLOOK

There are several options for climate-friendly industrial process heating. All these options have to be thoroughly investigated. A premature switch to all-electric heating solutions could be counterproductive for CO_2 emissions and overall cost. The energy system of the future will be based on regenerative power generation, but it will involve additional energy carriers to store and transport the energy. There are some challenges for combustion but there is no doubt that these can be overcome. A fair and open competition between the different energy options will create the best solutions for society. A planned economy will not provide the fertile soil for innovations and entrepreneurship, necessary to meet the challenges. **MS**

REFERENCES

[1] *CO_2-emissions of the German energy mix 1990-2018*, Federal Environmental Agency, 2019

[2] Domschke T, Becker C, and Wünning J G: 'Thermal Uuse of off gases with high ammonia content – a combination of Ccatalytic cracking and combustion', *Chem. Eng. Technol.*, *21*, 726-730, 1998

[3] Wünning J: 'Multistage Flameless Oxidation', *AFRC Combustion Symposium*, Waikoloa, Hawaii, September 2019

Joachim Wuenning is at WS Wärmeprozesstechnik GmbH

CONTACT: j.g.wuenning@flox.com