Delivering hydrogen steelmaking by better utilizing steam production

By replacing steam ejectors with mechanical vacuum pumps, steel plants can release steam production that can be more effectively used for hydrogen. This will support the move to zero carbon steelmaking

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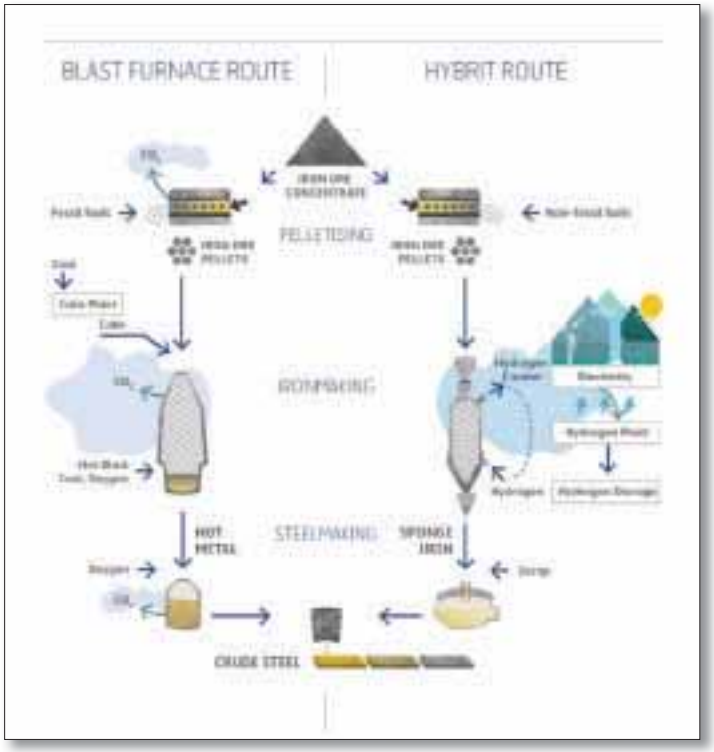

Fig 1 **Comparison of old and new production routes [1]**

INTRODUCTION

Steelmaking contributes about 10% of global CO_2 emissions and ultimately to global warming. This is a strong message for a material which is an integral part of our daily life. The main cause lies in the production of iron in the blast furnace, where iron ore is reduced by coal. This is energy intensive and ultimately results in the release of large amounts of CO_2 to the atmosphere. About 75% of global steel production comes from Blast Oxygen Furnaces, and the International Energy Agency (IEA) predicts an increase in steel demand of a third by 2050. "The 2020s are a very critical decade in this regard, as more than 70% of all blast furnaces are reaching the end of their useful life, and decisions about reinvestment will be necessary," says Wido Witecka, steel expert at the German climate protection think tank Agora Energiewende. These are strong arguments for the steel industry to strive for new, zero carbon technologies.

One option under discussion is Carbon Capture Storage (CCS). CCS involves the capture of carbon dioxide emissions from the processes, transport via ship or in a pipeline, and storage deep underground in geological formations. However, it is unclear how much of the emissions from steel production can be captured by CCS and at what cost.

HYDROGEN INSTEAD OF COAL AND GAS

The most promising option for decarbonizing ironmaking is the use of 'green' hydrogen as a replacement for coal and gas. Activities have already been started with large projects like Hybrit, involving SSAB, LKAB and Vattenfall. This project has, as a primary goal, creation of emission-free steel production by 2045 and reduction in total CO_2 emissions in Sweden by 10% and Finland by 7%.

The new hydrogen technology is destined to replace the blast furnace route. The preliminary product for steel production will be solid sponge iron, in the form of Hot Briquetted Iron (HBI), or Direct Reduced Iron (DRI), instead of the blast furnace's liquid pig iron. The by-product of this hydrogen process is water, instead of CO_2. This process necessitates a further change downstream, with steelmaking relying on large Electric Arc Furnaces (EAFs), ideally installed close to the DRI route to enable hot charging of DRI. A comparison of

the old and new production routes is shown in *Figure 1*.

For this process to be successful at decarbonizing steel production, it is crucial to use green hydrogen, which is understood to mean hydrogen produced by the electrolysis of water, with the electrical power supplied by renewable energy. This approach guarantees a CO_2 free product. The production of 1kg of hydrogen in an electrolysis process consumes between 40 and 80kWh, depending on the operational mode and the performance of the electrolyser. These figures relate to an efficiency of around 40 to 80%. A challenge is the provision of the required large amounts of energy from renewable sources, not only for electrolysis, but also for crude steel production.

STEAM PRODUCTION

Switching to green hydrogen-based steelmaking has wider implications for the downstream steelmaking production route: among others, the omission of steam production, as a byproduct from cooling of the blast oxygen furnaces. This steam is distributed in a grid all over the steel plant to supply various consumers. Likewise, steam can be produced as a byproduct from the heat of the EAF off-gas.

An example of what this means in terms of energy flow on the steel plant is shown in *Figure 2*. This example gives an insight into the distribution of heat loads on a typical 200t EAF resulting in 140kWh/t heat load in the off-gas, which can be converted to steam at a pressure of 25bar at 250°C. This is equivalent to 30t of steam. A decision then needs to be made about how best to utilize this steam.

Conventionally, a large consumer of steam produced by BOF cooling is the downstream secondary metallurgy vacuum plant, using the steam as propellant for large steam ejectors to create the process vacuum. Integrated steel mills are designed to process large quantities of liquid steel, and the subsequent refining stations are correspondingly large. In switching to an EAF, even more refining stations may be required, as the metallurgy will change. For example, an increased use of scrap and DRI may result in an increase in the sulphur level for the EAF, requiring additional secondary metallurgy treatments.

For vacuum applications, vacuum degassing and Ruhrstahl Heraeus degassing, steam was a cost-effective propellant to generate the mandatory vacuum in the tank, which is an extremely important consideration, in view of the size of the installations. However, there is already a trend in China to use mechanical vacuum pumps in integrated steel mills for new Ruhrstahl Heraeus refining stations. The steam produced as by-product of the BOF is then used for power generation.

MECHANICAL VACUUM PUMPS

Mechanical vacuum pumps are today state-of-the-art in the new refining stations of mini-mills using EAFs. Steam ▷

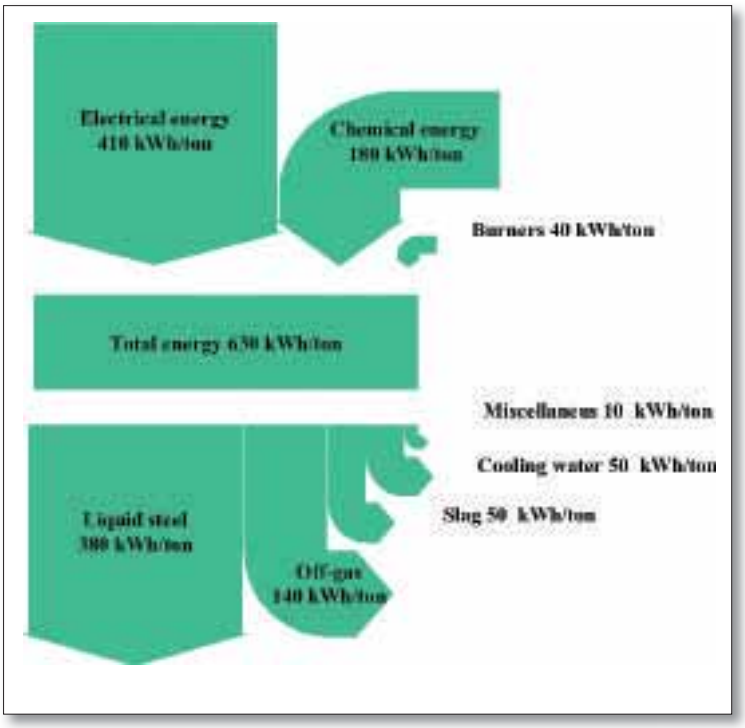

Fig 2 **Energy flow in 200t EAF operation [2]**

Fig 3 **Savings when using dry vacuum pumps vs steam ejectors**

Fig 4 **Mechanical Vacuum System for 150 ton Ruhrstahl-Heraeus refining station**

in these plants would need to be generated via a boiler, which would require additional investment, maintenance effort and high energy consumption. These conditions make mechanical vacuum pumps extremely attractive. The initial investment is higher, but as compared with a boiler, the costs of operation are significantly lower, leading to a rapid return on investment.

The specification for a typical new and efficient steam ejector system for an 80t VD refining station in India, has been shown to provide a pumping capacity of 200kg/h (DAE air 20°C equivalent) at 0.67mbar (hPa), and is designed to consume around 6600kg steam per VD cycle (around 98kg steam per tonne). This is shown in detail in *Figure 3*.

Further benefits of mechanical vacuum pumps are their stable and repeatable performance, which is independent of steam quality, or ambient temperature, which can impact the performance of liquid ring vacuum pumps, used in conjunction with steam ejectors. There is also no disposal of waste water and no long downtime for cleaning.

More than 30 years of field experience in global installations has proven the reliability of mechanical pumps (*Figure 4*). The technology has been optimized to lower energy consumption in the range of 1.3 to 2kWh per ton of steel, depending on the system design and performance requirements. In light of this low energy consumption, consideration should be given to using the steam generated from the EAF in a more effective way.

ELECTROLYSER

Production of DRI and HBI, extensive use of EAFs and integrated production of hydrogen onsite at the steel plant, necessitates high power requirements. It is therefore quite important to reduce electrical power consumption. The electrolysis of Hydrogen has a gigantic demand of electrical power. High-temperature electrolysis, which is under development, shows a great potential in using the

process steam of the steel to reduce the power consumption by c.20%. Electrolysers require energy from renewable sources to produce green hydrogen. The lower the energy consumption the better the electrolysers and other new technologies can be optimized as part of the process.

By using process heat to generate steam, or by using steam directly, the electrical energy consumption of an electrolyser can be reduced from 4.9kWh/Nm to 3.7kWh/Nm , a 20% reduction. If the operating temperature is further increased, in part by increasing the steam temperature and heating of the stack, only 2.4kWh/Nm are required at 800°C. This leads to a significant reduction in the required electrical connection power and the number of necessary regenerative energy generation systems.

CONCLUSION

Green steel produced with green hydrogen is a feasible modern technology to prevent the release of CO2 into the environment and to decarbonize the steel industry. The high demand of power from renewable sources can be optimized by well-thought out production arrangement and the use of innovative technology. Integrated steel mills must consider carefully every measure and technology, or new developments of technologies, like high temperature electrolysis, to find the optimized energy mix for the individual steel plant. Taking all considerations into account, it can be very effective to replace the consumption of steam for degassing by using mechanical pumps and releasing the steam for the hydrogen-electrolysis. MS

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