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Start-up and usage of coke oven gas at HKM on our mission to green steel saand CO_2 reduction

F. Perret, F. Demirci, A. Janz, R. Peter, T. Semleit, S. Schulte

By developing decarbonisation plans, the European steel industry shows its commitment to the European climate change targets. The main element in these plans is a transformation step involving a transition from carbon-based blast furnaces to green hydrogen-based direct reduction processes. This will take place around 2030 and will result in significant CO_2 reductions. Hüttenwerke Krupp Mannesmann (HKM) has committed itself to the European climate change targets and has already started to take actions to significantly reduce CO_2 emissions under the brand H2KM. As presented at the 8th ECIC in Bremen, HKM has upgraded its installation to inject compressed coke oven gas (COG) at the two blast furnaces "A" and "B". Since the injection station was commissioned and started in June 2023, HKM has been able to consistently inject up to of 45 kg/tHM of COG per month replacing PCI. This article discusses the usage of COG injection as an additional reducing agent for the blast furnace and presents results from start-up and data analyses on the injection, showing how it affects the blast furnace process and helps to reduce the carbon footprint of HKM's crude steel significantly.

KEYWORDS: CO_2 REDUCTION, BLAST FURNACE, COKE OVEN GAS, GREEN STEEL, HYDROGEN CONTAINING INJECTANTS

INTRODUCTION

The production of steel is one of the large emitters globally and responsible for 7% of global CO_2 emissions and around 5% of CO_2 emissions in the EU [1]. For every ton of steel produced in 2020, an average of 1.89 tons of carbon dioxide was emitted into the atmosphere [2]. At the UN Climate Action Summit 2019, more than 60 countries, including the EU, committed to full carbon neutrality by 2050 [3].

To understand and overcome the challenges faced by the European steel industry, it is first important to understand how steel is currently being made. In Europe, just over half of all steel is made by the primary route, where steel is being produced from iron ore in a process that centers on the use of carbon in the blast furnace.

Hüttenwerke Krupp Mannesmann GmbH (HKM) is an integrated steel mill in Duisburg, with the setup of coking plant, sinter plant, two blast furnaces (BF) and steel plant with Linz-Donawitz-converter (LD) operation. To achieve the climate goals assigned by the EU, HKM started the H2KM sustainability project, which consists of two phases. In the first phase CO_2-emissions are reduced within the

F. Perret, F. Demirci, A. Janz, R. Peter
Hüttenwerke Krupp Mannesmann GmbH, Germany

T. Semleit, S. Schulte
thyssenkrupp Steel Europe AG, Germany

current plant set up. Besides increasing recycling rates by installing ladle furnaces in the melt shop, utilizing COG injection is one of the major measures.
This paper discusses the usage of COG injection as an additional reducing agent for the blast furnace.

Reducing CO_2 by injection of COG

As already reported at the 8th ECIC & 9th ICSTI 2022 in Bremen [4], the main contract for the construction of the coke oven gas injection system for blast furnaces A and B was awarded to Paul Wurth S.A. in July 2020. The contract included the compressor building with the gear compressors, the drive technology, the EMSR technology, the modification of the furnace stations of the blast furnaces and the engineering services. The solid construction and infrastructure services were handled by HKM. This should allow HKM to inject up to 45 kg/tHM of COG per month continuously as a replacement for PCI. The injection station was commissioned and started up in June 2023. Figure 1 (a) shows the compressor station building and (b) one of the installed gear compressors. The existing natural gas injection plant had to be modified to allow the additional use of coke oven gas in both blast furnaces. With an annual hot metal production of around 4 million tonnes, a coke oven gas supply of 30,000-45,000 Nm3/h could be realised for both blast furnaces.

(a) (b)

Fig.1 - Compressor station building and (b) COG compressor.

The start-up phase of the COG system was carried out in collaboration with Paul Wurth S.A. and HKM. The gas injection was started slowly: The COG was fed into the compressor and the gas flow was gradually increased over a period of several weeks to ramp up to nominal operation. This also provided an insight into the reaction of the blast furnaces to the gas in order to set the optimum blast furnace parameters. Lastly, all relevant process parameters were set to the COG target values (45 kg/tHM) to ensure stable operating conditions in COG injection mode.

Effect of COG on the blast furnace process

In order to replace coal and coke with other fuels to reduce CO_2 emissions, alternative reducing agents to coal can be used in BFs, such as hydrogen and hydrogen-bearing gases, such as - COG. In particular, COG is a by-product of the coke plant process and is considered to be a viable alternative to pulverised coal (PC) in the BF. The COG has a high calorific value, a high hydrogen concentration (see Table 1) and a fast combustion rate. After cracking the CH4 in the blast furnace raceway, this results in a total hydrogen content of over 70 Vol.-%.

Tab.1 - Chemical composition COG HKM.

Elements	Vol.-%
H_2	63
CH_4	21
CO	6
N_2	6
CO_2	2
C_2H_4	2

However, the use of COG and other hydrogen-bearing fuels affects blast furnace process characteristics such as the Raceway Adiabatic Flame Temperature (RAFT), gas utilization (ηCO, ηH2), indirect and direct reduction, heat losses, and especially gas distribution and therefore the stability of the BF operation [5]. An online tool was developed for this purpose as part of the RFCS project H2TransBF2030 [6].

For a better visualisation of the influence of COG on the blast furnace process, an overview of selected process parameters (hot wind, pressure, stock line, top gas temperature, gas utilization, coke and COG amount, and heat loss) are shown in Figure 2 over a longer and stable production period of time (June 2024 to July 2024).

One of the first effects of COG on the blast furnace process is a change in the use of reducing agents. By using COG, the coal injection rate can be decreased. However, the amount of coke remains constant to ensure stable operation of the blast furnace process in terms of drainage, etc..

Besides the effect of the COG on the reducing agent consumption, the gas also has an impact on the RAFT. To keep the RAFT at a good level, the specific oxygen injection rate and therefore the productivity will be increased. It can be expected that the blast furnace top gas volume flow will be reduced by almost 8% and its gas composition will be changed towards a higher hydrogen content, increasing the calorific value by about 15%.

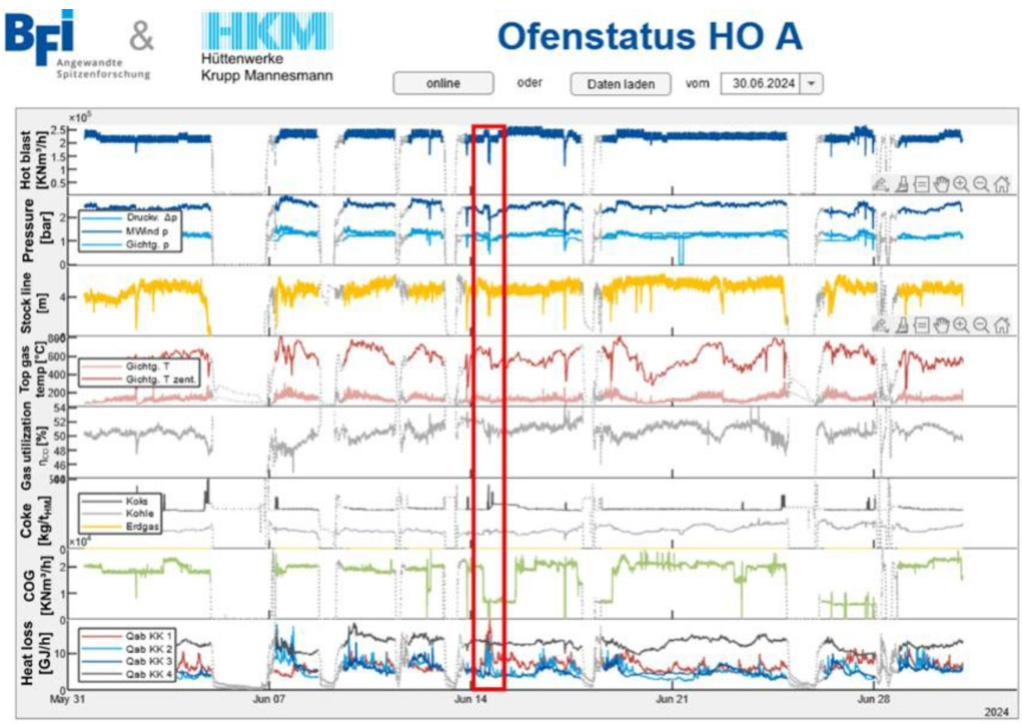

Fig.2 - Effect of COG on blast furnace process parameters.

When using COG at HKM, it can also be observed that the gas has a particular influence on the heat losses of the blast furnaces. This influence on the heat losses is shown in more detail and is highlighted by the red box. The more detailed COG curve is shown in Figure 3.

When the full amount of COG injection is turned off and changed with PCI, there is an increase in the heat losses of blast furnace A, while the gas utilization (ηCO) decreases. This behaviour can be explained by taking into account the water gas shift reaction (WGSR) and the influence of hydrogen on both the direct and indirect reduction. Particularly in the lower area of the furnace (bosh region), where a large part of the direct reduction work takes place, the processes and reduction procedures change enormously due to the altered composition of the reduction gas.

With regard to the gas utilization ηCO, it becomes clear that the mathematical ratio of CO_2 to CO changes here. In the normal blast furnace process with a low proportion of hydrogen-containing reducing gas, ηCO can be used as a measure of gas utilization for reduction. If a larger amount of hydrogen-containing reducing gas is used, the significance of ηCO decreases significantly, as the water-gas shift reaction turns the CO gas into CO_2 without having removed oxygen from the iron ore. The informative value of ηCO as a measure of the reduction work in the blast furnace is therefore reduced. For an operating mode with reducing gases containing high hydrogen content, ηH2 must also become more important.

The high hydrogen content in coke oven gas favours the indirect reduction of iron oxides, as hydrogen (H_2) is a more reactive reducing agent than carbon monoxide (CO), resulting in an increased rate of indirect reduction when hydrogenous gases are injected [6].

Another effect of coke gas is a change in the temperature profiles (isotherms) of the blast furnace due to the change in RAFT, mainly the indirect and cohesive zone. The indirect reduction zone increases, while the cohesive zone moves upwards, resulting in a much more efficient use of the furnace volume.

As a result, the size of the indirect reduction zone expands while the amount of unreduced FeO reaching the lower part of the blast furnace decreases. This results in more efficient operation of the lower furnace as the majority of the FeO has already been converted by the indirect reduction. Hence the proportion of direct reduction is reduced, leading to better slag discharge and fuel consumption. Another major advantage of coke gas injection is that there is no need to burn a solid material (PC) with residues. In classic PC-injection, the injection coal is not burnt without residue, but leaves behind char and coke ash in the combustion process, which mainly has to be processed in the hearth. With gas injection, there is residue-free combustion, which is good for the health of the hearth and the purity of the dead man. The result is increased permeability in the lower, with clear advantages for process stability.

Once the cohesive zone and the lower furnace have adjusted to a reducing gas composition (here, with coke gas and PCI), the processes run in equilibrium. When the coke gas injection is switched off and the switch is made to pure PCI, the following picture is shown in Figure 3. The pressure increases slightly throughout the furnace process. The processes in the lower furnace are no longer in equilibrium. Due to the now significantly lower proportion of H2-containing reducing gas, which was available for direct reduction in particular, the CO-containing gas or coke must now perform the direct reduction work. A large amount of coke from the cohesive zone is consumed for this purpose. As a result, the gas flow in the area of the dead man, the cohesive zone and the external coke windows deteriorates. This leads to heat losses in the lower furnace, which causes the furnace process to become unstable. A stabilization of the furnace can only be seen after the coke rate has been increased and a period of approx. 2-3 furnace throughputs. After this, the processes in the lower furnace are back in equilibrium and have adapted to the reduction gas (pure PCI operation).

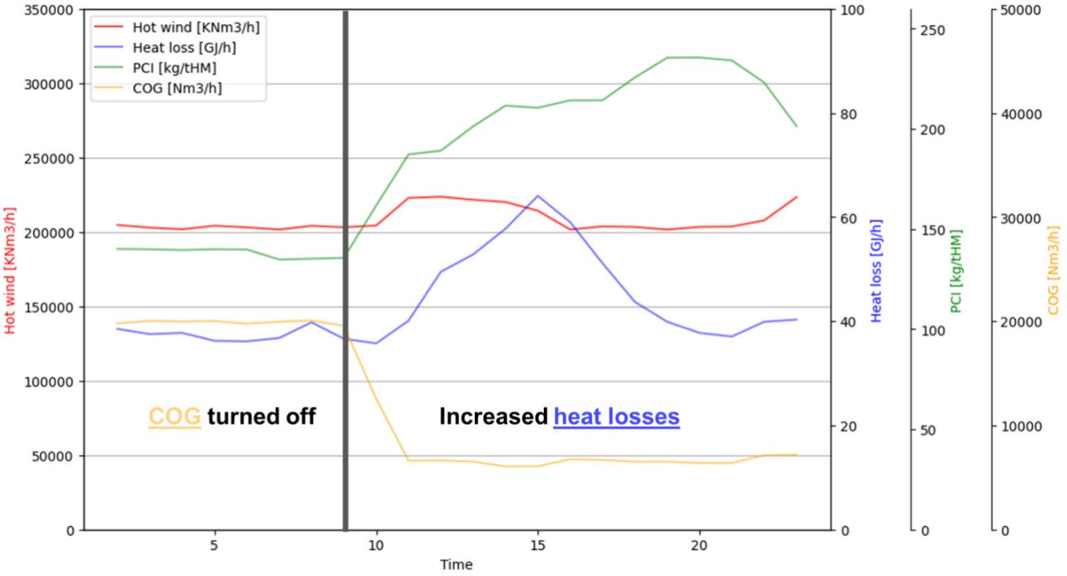

Fig.3 - Effect of COG reduction on blast furnace process parameters.

CONCLUSION

Overall, coke gas injection can contribute as a successful measure to the partial decarbonisation of hot metal production and serve as a bridge technology to CO_2-free steel production.

Coke gas injection has no negative impact on the blast furnace process, but increases both the efficiency and productivity of the blast furnace. The process itself is more stable, as hydrogen as a reducing gas supports and accelerates the existing CO reduction. The only factor that should not be underestimated in the design is the increased use of oxygen to set a usable flame temperature and the associated increase in output.

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