Optimization strategies for pulverized coal injection into the blast furnace

Optimierungsstrategien zum Einblasen von Kohlenstaub in den Hochofen

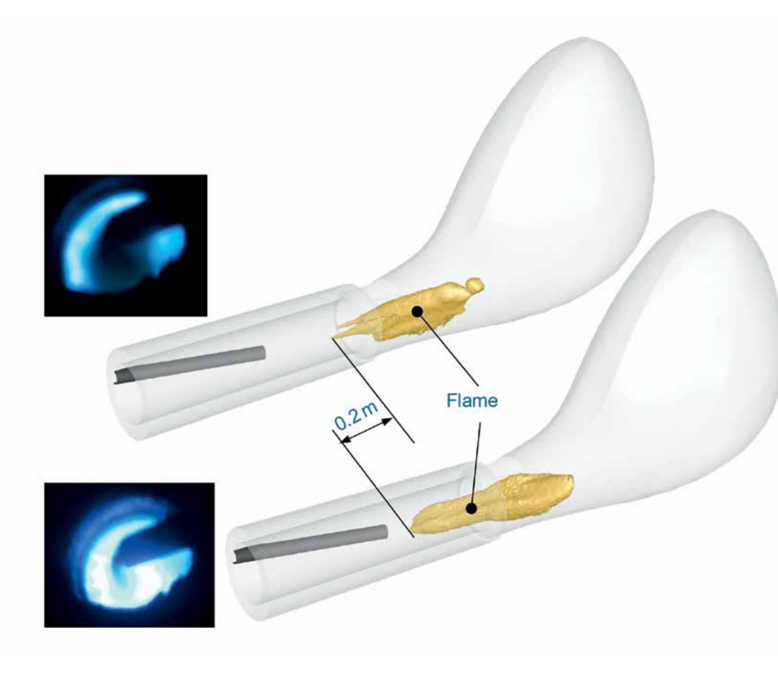
Robin Schott

A significant measure to improve cost effectiveness of the blast furnace process by reducing the coke rate was the injection of pulverized coal into the raceway of the blast furnace. For an optimal blast furnace operation using pulverized coal injection (PCI), it is necessary that the injected coal is gasified as fast and efficiently as possible within the tuyère and the raceway of the furnace. This paper focuses on some important steps of these PCI improvements accelerating PC gasification. Finally, the economic aspects of using PCI considering the presented optimization steps will be discussed.

Das Einblasen von Kohlenstaub in die Wirbelzone des Hochofens ist eine bedeutende Maßnahme zur Reduzierung des Kokssatzes und damit zur Senkung der Brennstoffkosten. Für einen optimalen Hochofenprozess ist es notwendig, dass der eingeblasene Kohlenstaub so schnell und gut wie möglich innerhalb der Blasform und der Wirbelzone des Hochofens vergast wird. Der vorliegende Beitrag fokussiert sich daher beispielhaft auf einige wichtige Entwicklungen zur Beschleunigung der Vergasung beim Einblasen von Kohlenstaub. Dabei werden auch wirtschaftliche Aspekte diskutiert.

The blast furnace process is the most important process to produce crude iron. The required process energy is mainly covered by coke which is expensive. A significant measure to improve cost effectiveness by reducing the blast furnace coke rate was the injection of cheaper auxiliary reducing agents like pulverized coal, oil or natural gas into the raceway of the blast furnace. More than 60 % of all blast furnaces in the world use pulverized coal injection (PCI), while only 3.7 % use oil, 10.9 % use natural gas and 2.6 % use other auxiliary fuels like charcoal fines, tar, plastic or coke oven gas [1]. 22.5 % use no auxiliary reducing agent at all. These are rather small or old, making the cost effectiveness of an application of auxiliary reducing agent injection questionable.

The greatest influence on cost effectiveness using auxiliary reducing agents is the price difference between coke and the auxiliary reducing agent and the maximal possible injection rate converted in the blast furnace process. Most blast furnaces in the world use pulverized coal as an auxiliary reducing agent as the cost-efficiency enhancement is the best in their cases. Figure 1 shows a simplified calculation



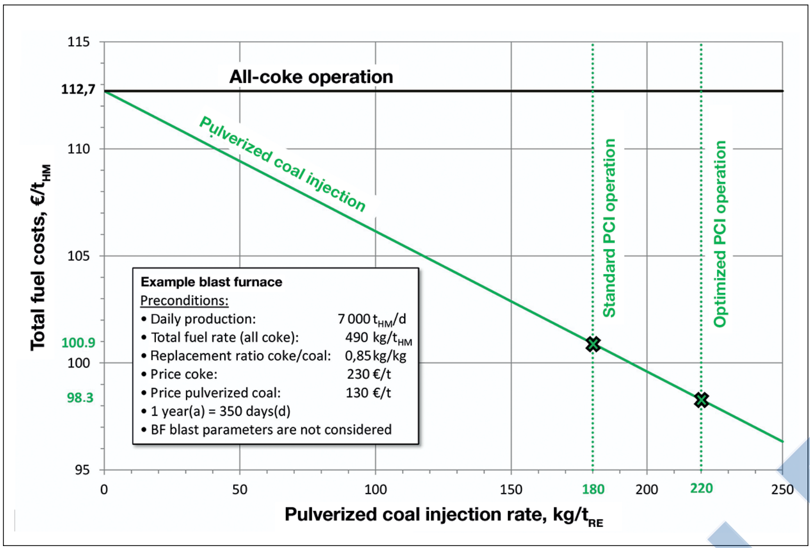
Graphic: Küttner

Improved coal gasification using PCI at the blast furnace
Verbesserung der Kohlenstaubvergasung beim Einblasen in den Hochofen

of total fuel costs depending on the pulverized coal injection rate for an exemplary blast furnace with a daily production rate 7 000 t_{HM}/d and a total fuel rate of 490 kg/t_{HM}.

This calculation shows as the pulverized coal injection rate is increased an increasing cost reduction of the total fuel costs compared to an all-coke operation of the blast furnace.

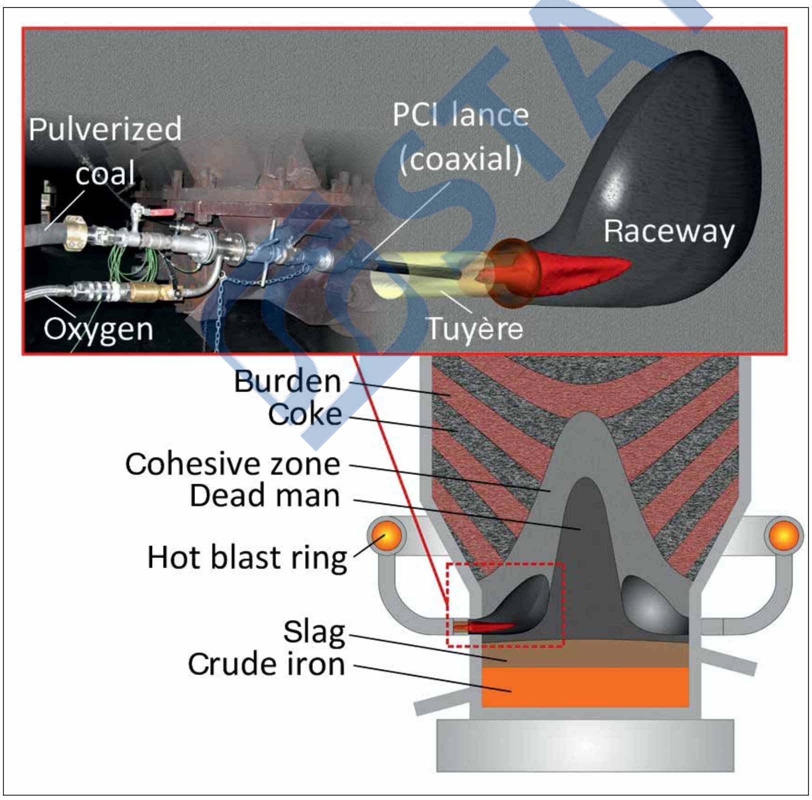
Consequently a requirement for the PCI technology is to ensure the highest possible injection rate which is converted in the blast furnace process. In order to achieve this target, the consideration starts with the pulverized coal gasification process within the tuyère and the raceway of the blast furnace, figure **2**.



1

Cost-efficiency enhancement of PCI use versus all-coke operation

Wirtschaftliche Effizienzsteigerung durch PCI verglichen mit dem Nur-Koks-Betrieb



2

Pulverized coal injection through the tuyère into the raceway of the blast furnace

Einblasen von Kohlenstaub durch die Blasform in die Wirbelzone des Hochofens

PCI technology requirements

For an optimal blast furnace operation using pulverized coal injection, it is necessary to ensure that nearly the whole amount of injected coal is gasified as fast and best as possible. For this purpose, only 10 – 20 ms are available after pulverized coal is injected into the hot blast within the tuyère, and before the pulverized coal enters the coke layers at the end of the raceway. In this short period of time, the injected coal particles heat up to ignition temperature and gasify. Pyrolysis, combustion of pyrolysis gases and gasifying of generated semi-coke occur simultaneously. A portion of the generated semi-coke enters the coke layer at the end of the raceway, where it then gasifies. This amount should be as small as possible; otherwise, it could negatively affect the permeability of the blast furnace. The physical and kinetic limits of coke substitution for pulverized coal are the permeability of the blast furnace if the injected pulverized coal does not gasify completely, a minimum coke rate to secure the permeability of the blast furnace, and/or an increasing amount of unconverted pulverized coal in the top gas dust. Hence, the injected pulverized coal rate can be increased, and the coke rate can be simultaneously decreased (according to the replacement ratio coke/coal), as long as the pressure drop in the blast furnace or the carbon rate in the top gas dust does not increase significantly [2; 3].

Consequently, the pulverized coal injection technology should be developed with a vision of the best possible gasification of injected pulverized coal within the tuyère and raceway of the blast furnace. The main goals of development are [3]:

- ▷ The retention time of the injected pulverized coal particles has to be maximized. Therefore, the speed of injected coal particles has to be reduced to a minimum.
- ▷ The nitrogen ingress into the blast furnace via the pulverized coal injection system has to be minimized, as nitrogen does not contribute to the gasification of carbon, or to the reduction of iron oxides within the blast furnace process. To achieve this, the transport gas loading of pulverized coal injection has to be maximized.
- ▷ The gasification of carbon needs oxygen and a large surface so that the reaction can take place at as many places simultaneously as possible. Therefore, the oxygen level in the coal cloud has to be maximized by a good mixing of the injected coal

and the hot blast and/or by the Oxycoal technology (which will be discussed later in this paper). In order to create a large reaction surface, the injected coal particle has to have a small mean diameter.

- ▷ The starting time of injected pulverized coal gasification within the tuyère can be shortened by a high concentration of oxygen in the gas surrounding the injected coal cloud. For this reason, oxygen has to be brought close to the injected coal particles by the Oxycoal technology. Furthermore a high oxygen level next to the injected coal particles accelerates the speed of coal gasification.
- ▷ An additional way to induce an early start and acceleration of coal gasification is the preheating of the pulverized coal before injecting into the tuyère and raceway of the blast furnace.
- ▷ The stability of the injection process is very important, requiring an even distribution to all tuyères of the blast furnace and no pulsation.

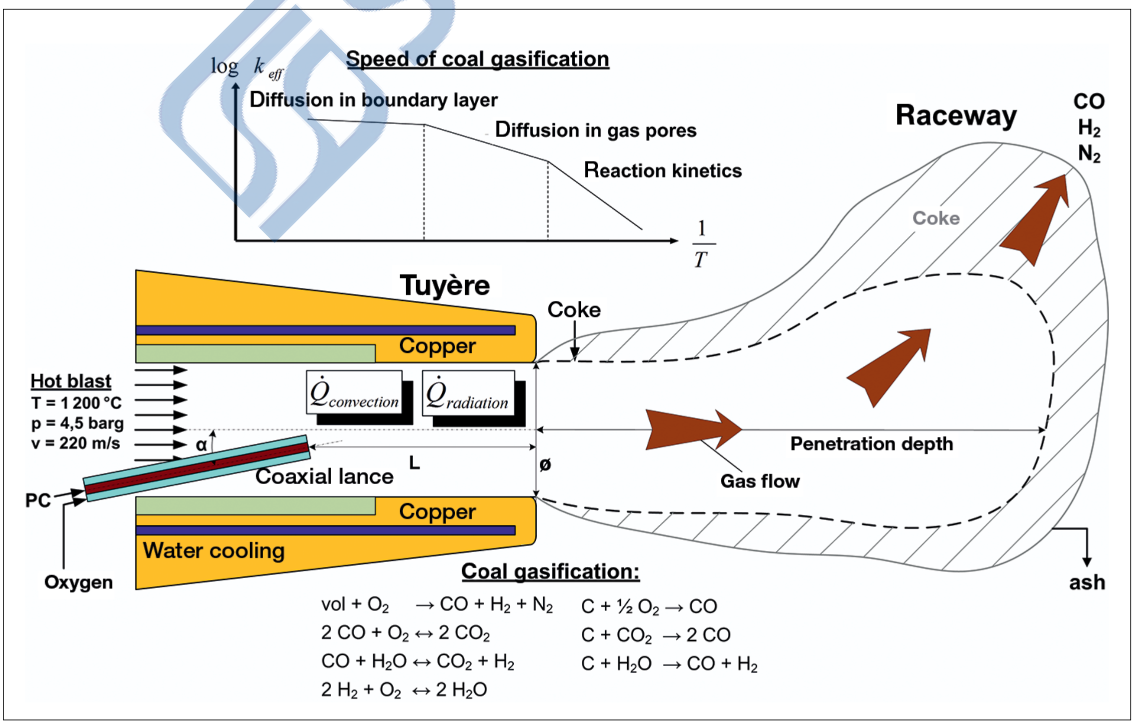
There are other important influences on a high pulverized coal injection rate and low coke rate operation of the blast furnace, like the quality of the burden raw materials. For example, the coke quality parameter CSR (coke strength after reaction) has a big influence on pulverized coal injection rate and total fuel consumption. A good overview of this topic can be found in [4].

Another way to realize high pulverized coal injection rates converted in the blast furnace process uses high oxygen enrichments of the hot blast of more than 30 to 35 %. The more oxygen enrichment of the hot blast the better is the gasification of coal particles blown in the coke layer at the end of the raceway. That means that a fast gasification of injected pulverized coal in the tuyère and the raceway is less important because a higher amount of not converted coal particles can be gasified in the coke layers at the end of the raceway by the additional oxygen in the hot blast. The permeability and the pressure drop of the blast furnace is not affected negatively and the amount of carbon in the top gas does not increase. In the end a high oxygen enrichment of the hot blast enables to achieve high PCI rate even with a simple PCI technology.

But it has to be considered that a lot of oxygen is needed for a high oxygen enrichment of the hot blast. For example an oxygen enrichment of 35 % with a total amount of hot blast of approx. 710 m³ (S.T.P.)/t_{HM} needs 125.82 m³ (S.T.P.)/t_{HM} of pure oxygen. In most place of the world oxygen is expensive. Of course more oxygen in the hot blast of the blast furnace enables more crude iron to be produced. However, this operation could mean higher wear for the blast furnace. In the end a detailed technological and economic analysis is necessary to decide about a traditional operation or an operation with a high oxygen enrichment of the blast furnace.

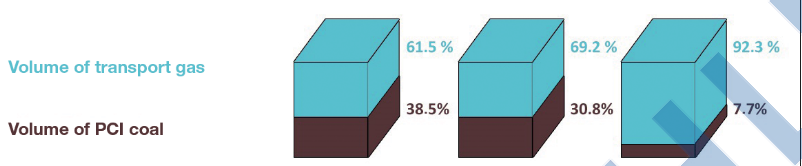
Methods of evaluation

If PCI technology is used it is very important to evaluate its technological and economic success. The most reliable PCI evaluations are of course operational results. But operational PCI results can only be determined after installation of the corresponding PCI technology at the blast furnace. Furthermore it is very difficult or in some cases impossible to determine reliably measured values for example inside the raceway. For the decision which PCI technology or which possible PCI



3 **Küttner's gas flow and PCI process model of the tuyère and the raceway [5]**

Küttners Strömungs- und Kohlenstaubeinblasmodell der Blasform und der Wirbelzone [5] optimization strategy should be used it is necessary to forecast the performance of the corresponding PCI technology and its effect on the blast furnace process. That is the reason why Küttner developed its own gas flow and PCI process model of the tuyère and the raceway of the blast furnace [5]. When using PCI at the blast furnace it is very important that as much pulverized coal as possible is converted as fast as possible within the tuyère and the raceway. Thereby, the speed of coal gasification depends on the temperature and is determined by either the chemical kinetics or the diffusion in coal particle pores or the diffusion through the particle encircling interface. The reaction space in the tuyère is known explicitly, see figure 3, whereas the shape of the reaction space in the raceway can be traced back on endoscopic researches made by Greuel et al. [6]. The penetration depth of the raceway is calculated in dependence of the kinetic energy of the hot blast according to the semi-empirical model of Peters [7]. The three-dimensional gas flow is described by steady-state Reynolds-averaged conservation equations for mass, substance, momentum, and energy. The coal particles are modelled as a disperse phase according to the Lagrange method. That model calculates injected coal particle characteristics on the basis of a balance of forces along discrete trajectory at which particle-particle interactions are disregarded. The heating of the disperse phase is modelled by radiation and convective flow of heat. For the description of the burnout of injected coal particles a standard coal combustion model is used, in which the Boudouard reaction and the heterogeneous water-gas reaction are added to the heterogeneous surface reactions, like the partial oxidation of carbon. The transport of the different gases within the gaseous phase and their reactions among each other is described by the finite rate/Eddy dissipation model, in which the speed of reaction is either limited by the Arrhenius rate dependent on temperature or by turbulent mixing of the reacting agents. The complexity of that physical model is down to simultaneously solving the formulation of the three-dimensional two-phase flow superimposed by the coal gasification reactions, and considering heat radiation and convection. To solve the resulting complex system of equations a computational fluid dynamic (CFD) tool [5] is used.



	PCI coal in silo	Dense phase	Dilute phase
Density	500 kg/m³	400 kg/m³	100 kg/m³
Pressure (tuyère)	0 bar g	4 bar g	4 bar g
Gas loading		70 kg/kg	10 kg/kg
Transport gas in BF		11.5 m³ (S.T.P.)/t_{coal}	80 m³ (S.T.P.)/t_{coal}
Velocity		2-6 m/s	15-20 m/s
Wear		**No wear**	**High wear**

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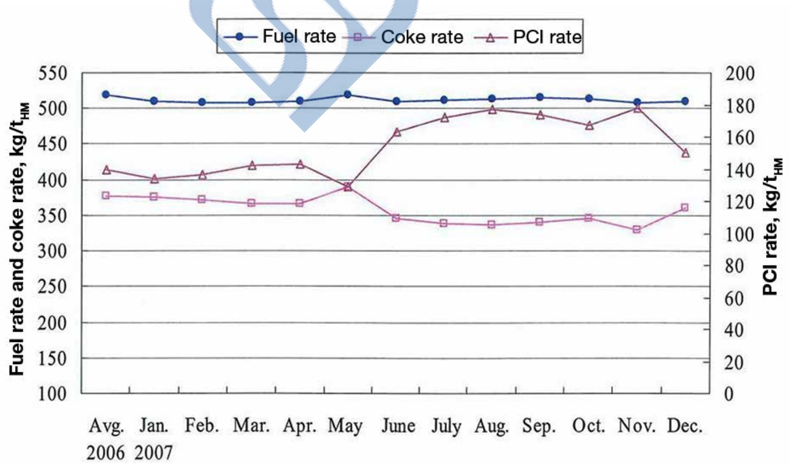
Dense-phase conveying versus dilute-phase conveying

Vergleich zwischen Dichtstrom- und Flugstromförderung



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PCI, coke and total fuel rate of BF No 4 in 2007 at CSC, Kaohsiung, Taiwan [8]

Kohlenstaubeinblas-, Koks- und Gesamtbrennstoffrate am HO 4 bei CSC, Kaohsiung, Taiwan, 2007 [8]

PCI optimization strategies

Küttner's first industrial pulverized coal injection plant was built in 1984/85 for Thyssen's blast furnace No 4 in Duisburg-Hamborn, Germany. At that time, Küttner started with its own dense phase PCI system, while others favoured a dilute phase PCI system. In 1984 Thyssen decided to equip blast furnace No 4 in Hamborn in such a way that 15 tuyères were fed with Küttner's dense phase PCI system, and the other 15 tuyères with a dilute phase system. But what is the difference between a dilute phase and a dense phase PCI system? Figure 4 gives an answer to that question.

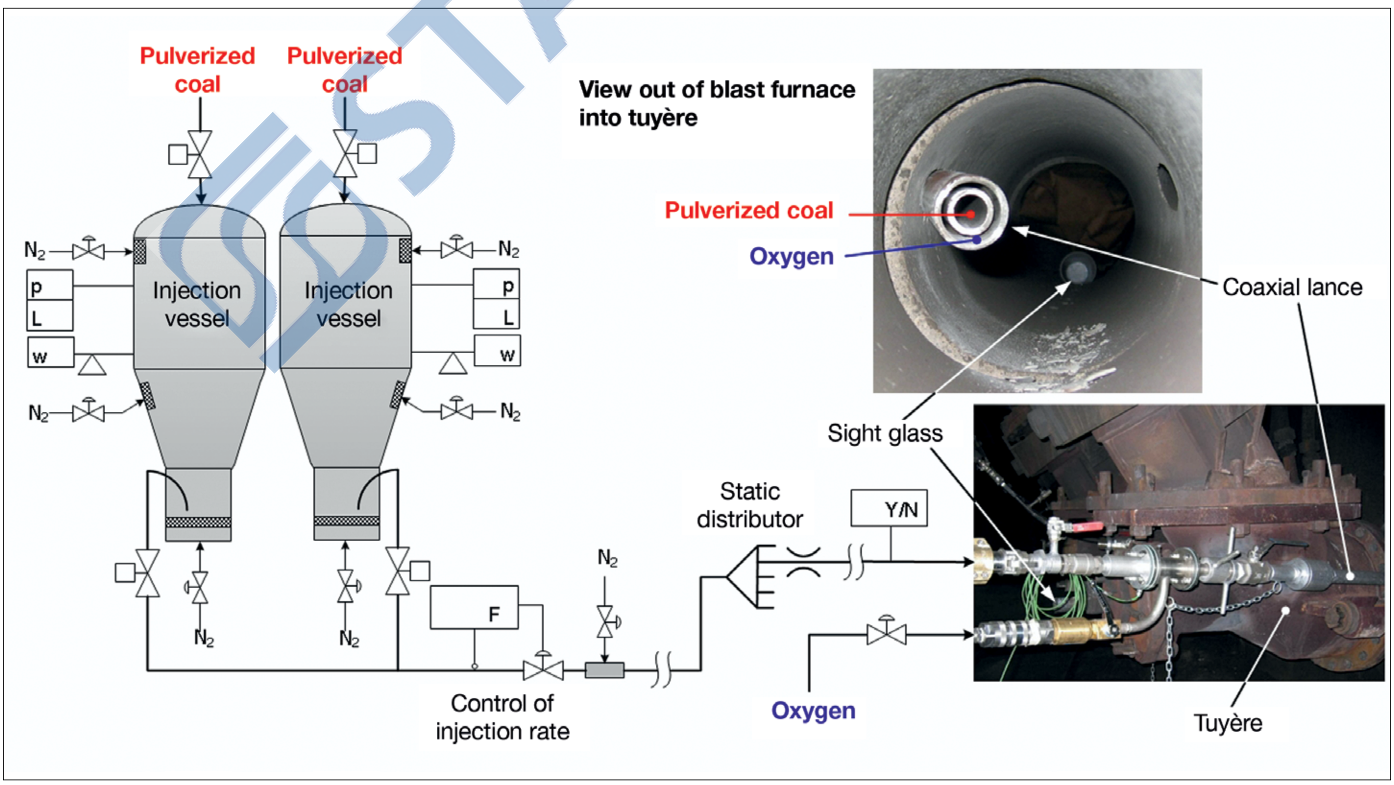
The main difference between a dilute phase and dense phase PCI system is the amount of gas that is used for conveying and injection. Pulverized coal in a silo has a bulk density of approx. 500 kg/m³. That means only 38.5 % of the silo volume is filled with pure coal, and 61.5 % of the silo volume is filled with gas that is between the coal particles. For dense phase conveying and injection, only a small amount of transport gas will be added in such a way that the density is approx. 400 kg/m³. This means that the portion of coal volume in the conveying/injection pipe is 30.8 %, and that of transport gas is 69.2 %. For dilute phase conveying and injection, a density of 100 kg/m³ can be assumed. This means that the portion of coal volume in the conveying/injection pipe is only 7.7 %, and that of transport gas is 92.7 %. Considering a counter pressure of 4 barg in the blast furnace tuyère, a dense phase injection can be operated at a transport gas loading of 70 $kg_{coal}/kg_{transportgas}$; while a dilute phase injection is normally operated at a transport gas loading of 10 $kg_{coal}/kg_{transportgas}$. As a consequence, the amount of transport gas (nitrogen) injected in the blast furnace in a dense phase system is only 11.5 m^3(S.T.P.)/t_{PC}; whereas, a dilute phase system is 80 m^3(S.T.P.)/t_{PC}. Furthermore, the transport velocity in a dense phase system is between 2 and 7 m/s. Due to this low transport velocity, there is nearly no wear in the transport pipe. A dilute phase system is usually operated with a transport velocity between 15 and 20 m/s, which causes considerable wear in the transport pipes.

Figure 5 illustrates the positive effect on the blast furnace process of using dense phase PCI technology compared to dilute phase PCI technology. In May 2007 Küttner executed an upgrading project at China Steel Corporation (CSC) in Kaohsiung, Taiwan [8]. During this project the existing dilute phase PCI system of blast furnace No 4 at CSC was upgraded with the Küttner dense phase technology. Figure 5 shows that the PCI rate was increased from about 145 kg/t_{HM} using dilute phase PCI technology to maximum 178 kg/t_{HM} using dense phase PCI technology. The total fuel rate stayed on the same level. Altogether, the advantages of dense phase PCI technology compared to dilute phase PCI technology are obvious.

The first step of optimizing existing PCI systems is to reduce the transport and injection gas to a minimum or in other words to use dense phase PCI technology. Figure 5 illustrates operational results of the increased PCI and decreased coke rate related to CSC blast furnace No 4.

Normally customers like to have a forecast of the possible increase of PCI rate. Küttner is able to do this with the help of Küttner's gas flow and PCI process model of the tuyère and the raceway [5] (see above). Further down an example PCI rate forecast comparing dilute phase and dense phase injection is shown. An additional increase of the PCI rate associated with a decrease of coke rate can be achieved by using the Oxycoal technology. Figure 6 shows schematically a dense phase PCI system which is equipped with the Oxycoal technology. Here a part of the hot blast oxygen enrichment is directly injected, combined with the pulverized coal via coaxial lances into the blast furnace tuyères. Basically a coaxial lance consists of two straight pipes stuck into each other. Pulverized coal is injected through the inner pipe while oxygen is injected through the coaxial gap between inner and outer pipe, see upper photo of figure 6. It is important that oxygen does not come into contact with the pulverized coal until they are injected into the hot blast within the blast furnace tuyère.

The idea behind covering the injected pulverized coal with oxygen is to increase the partial pressure of oxygen directly at the coal particle. As a consequence, the gasification of the coal particle will be accelerated. Beyond that pure oxygen lowers the ignition temperature of the coal particles, which accelerates



6

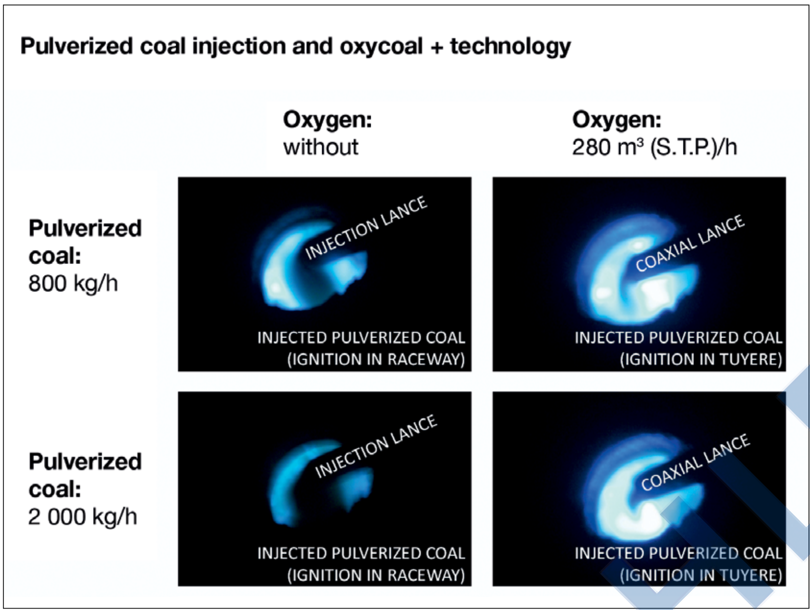
Küttner's Oxycoal technology | *Küttners Oxycoal-Verfahren* the start of coal gasification [9]. The gasification of the injected coal particle starts right after being heated up to ignition temperature short after leaving the lance within the tuyère. A simultaneous, visible temperature increase in the tuyère is expected.

This increase of temperature within the tuyères can be observed at the blast furnace operating dense phase PCI with Oxycoal technology. Figure 7 shows four photos taken through a sight glass at tuyère No 8 of blast furnace No 5 at Rogesa Roheisengesellschaft Saar mbH in 2005, which was equipped with the Küttner dense phase and Oxycoal technology. The sight glass is arranged in a way that one can look through the tuyère into the raceway of the blast furnace. The photos on the left side of figure 7 show the injected pulverized coal at an injection rate of 800 kg/h (top) and of 2 000 kg/h (bottom). On both photos, a black cloud of injected and not yet ignited pulverized coal can be seen. The photos on the right side show the same tuyère and the same PCI rate, but with an additional oxygen injection of 280 m³(S.T.P.)/h according to the Oxycoal technology. On these photos, no black pulverized coal cloud can be detected. The injected pulverized coal is very bright since the volatiles from the coal have ignited right after the coal particles were injected into the hot blast within the tuyères. That implies that the injected pulverized coal had already started to gasify in the tuyère. Measurements and calculations show temperatures of up to 2 400 °C within the tuyère [2].

Altogether the gasification of injected coal will be accelerated using the Oxycoal technology. It can therefore be concluded that the injection rate of pulverized coal can be enhanced without negatively affecting the gas flow through the blast furnace. Corresponding to the increase of the injection rate, the coke rate of the blast furnace can be decreased according to the replacement ratio coke/coal.

The second step of optimizing existing dense phase PCI systems is to improve the PC gasification within the tuyère and the raceway by using the Oxycoal technology. The remaining question is to quantify the increase of injection rate using the Oxycoal technology compared to dense phase PCI and to dilute phase PCI. Therefore, Küttner's gas flow and PCI process model of the tuyère and the raceway [5] (see above) is used.

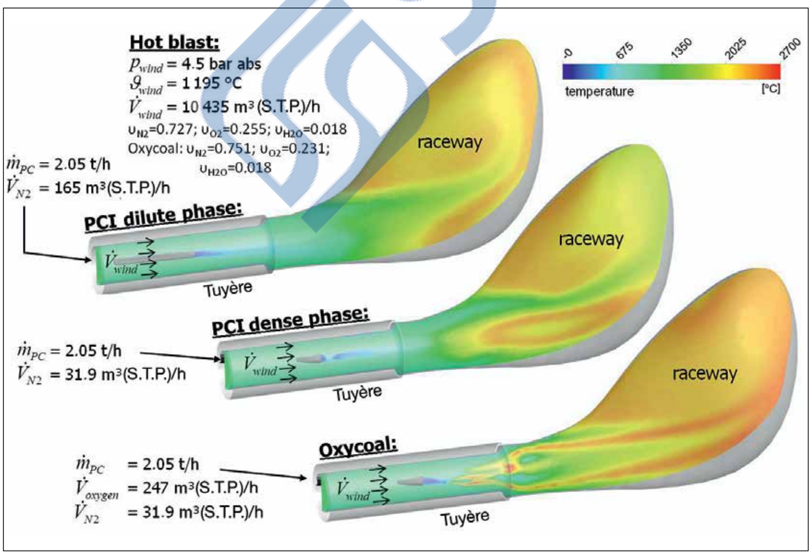
Figure 8 shows the results of three numerical simulations, one for dilute phase PCI, one for dense phase PCI and one for dense phase PCI using the Oxycoal technology. The dilute phase PCI simulation acts as reference. This means that the dilute phase simulation is fitted to a real dilute phase PCI operation at a blast furnace. Furthermore it is important that, for all three numerical simulations, the injected amount of pulverized coal and all hot blast parameters especially the amounts of oxygen are the same. This means that the oxygen amount blown through the coaxial lance using Oxycoal technology was detached from the oxygen enrichment of the hot blast. The results of the numerical simulations in figure 8 are illustrated on a two-dimensional plane in the middle of the reaction space within the tuyère and the raceway. These results show the temperature distribution, indicating the burning of injected pulverized coal.



7

Influence of Oxycoal on coal gasification in the tuyère and the raceway of the blast furnace

Einfluss der Oxycoal-Technik auf die Kohlenstaubumsetzung in der Blasform und der Wirbelzone des Hochofens



8

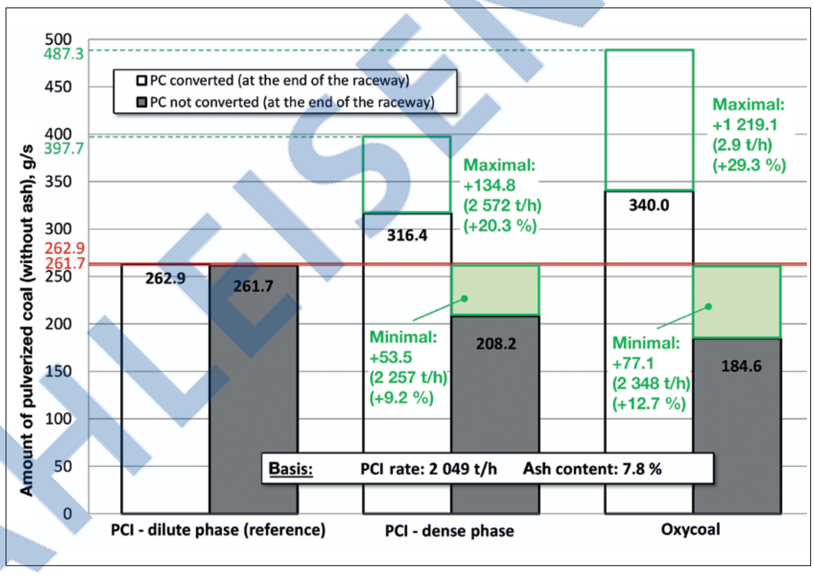
PCI simulation results from dilute phase versus dense phase versus Oxycoal technology

Vergleich der PCI-Simulationsergebnisse zwischen Flugstrom, Dichtstrom und dem Oxycoal-Verfahren

Regarding the temperature distribution, it can be seen that the increase of temperature using dilute phase PCI occurs deep within the raceway; whereas, using dense phase PCI show the increase of temperature next to the tuyère but still within the raceway and not in the tuyère. Using dense phase PCI with Oxycoal technology, the increase of temperature occurs within the tuyère. The result concerning the start of ignition of injected pulverized coal within the tuyère corresponds exactly to the experimental observations shown in figure 7. Altogether these results confirm that coal gasification starts earlier using dense phase PCI compared to dilute phase PCI and even earlier still using the Oxycoal technology. Consequently, there is more time left for a complete gasification of the injected coal particles within the tuyère and the blast furnace raceway. The numerical simulations can also be evaluated to quantify the more complete gasification of injected coal particles using dense phase and/or Oxycoal technology. In doing so the not converted coal particles at the end of the raceway just before entering the coke layer in the blast furnace are counted. This is shown in figure 9 where the amount of completely and incompletely gasified coal particles within the tuyère and raceway is evaluated for all three numerical simulations.

The results of this evaluation show that for the dilute phase simulation (reference) half-odd of injected pulverized coal (262.9 g/s) is gasified completely in the tuyère and raceway. The other half (261.7 g/s) enters the coke layer at the end of the raceway. Remember the reference simulation was fitted to a real dilute phase PCI operation at the blast furnace. This implies that the blast furnace process is able to cope with the amount of not completely converted pulverized coal particles of 261.7 g/s entering the coke layer at the end of the raceway. If now the dilute phase PCI is changed to the dense phase PCI and afterwards to the dense phase PCI using the Oxycoal technology the numerical results in figure 9 show that the amount of pulverized coal converted completely in the tuyère and raceway increased from 262.9 g/s (dilute phase) to 316.4 g/s (dense phase) and to 340 g/s (Oxycoal) while the amount of incompletely converted pulverized coal entering the coke layer at the end of the raceway decreased from 261.7 g/s (dilute phase) to 208,2 g/s (dense phase) and to 184.6 g/s (Oxycoal). From this it can be concluded that a minimal increase of PCI rate changing dilute phase PCI to dense phase PCI of 53.5 g/s (or 9.2 %) as the blast furnace process can cope with 261.7 g/s of incompletely converted pulverized coal entering the coke layer at the end of the raceway (reference). In this case the minimal amount of additionally injected pulverized coal of 53.5 g/s is not gasified in the tuyère and raceway but it is very probable that this additional amount of injected pulverized coal is also gasified according to the ratio converted to not converted coal using dense phase PCI. From this a maximum increase of PCI rate of 134.8 g/s (or 20.3 %) using dense phase PCI instead of dilute phase PCI follows. The truth is somewhere between the minimum and maximum increase of the PCI rate. For dense phase PCI using the Oxycoal technology the minimum increase of the PCI rate compared to dilute phase PCI is evaluated to 77.1 g/s (or 12.7 %) and the maximum increase of the PCI rate is evaluated to 219.1 g/s (or 29.3 %).

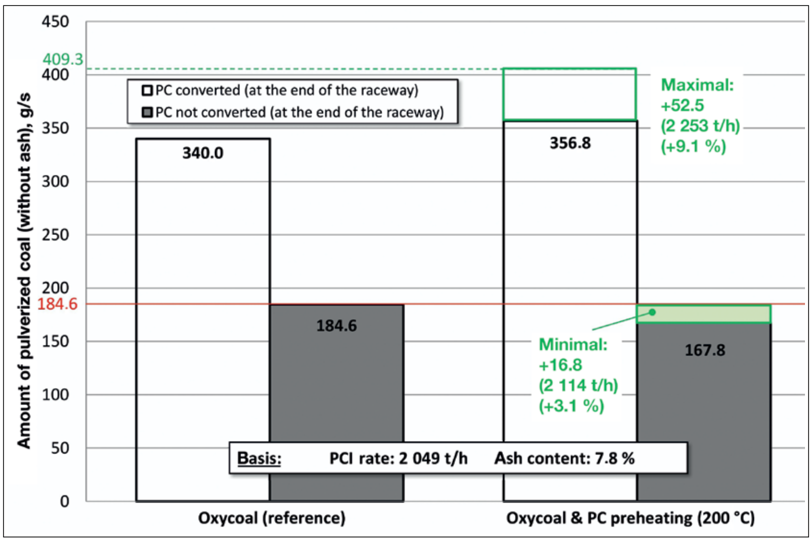
In addition to this, a further reduction in costs by a further increase of PCI and decrease of coke rate can be achieved by preheating the pulverized coal before injection. In this way the speed of coal



9

Improved coal gasification from dilute phase versus dense phase versus Oxycoal technology

Verbesserte Kohlenstaubvergasung vom Flugstrom über Dichtstrom bis zum Oxycoal-Verfahren



10

Improved coal gasification from Oxycoal versus Oxycoal incl. PC preheating (200 °C)

Verbesserte Kohlenstaubvergasung von nur Oxycoal bis Oxycoal mit Vorwärmung des Kohlenstaubs (200 °C) ignition and gasification within the tuyère and the raceway will additionally be accelerated. Preheated pulverized coal reduces time for heating up the coal particles to ignition temperature inside the tuyère and raceway and extra sensitive heat will be supplied to the blast furnace process. Residual surface moisture can be evaporated and partly released outside the blast furnace. In doing so steam cracking energy supplied by the blast furnace process is also saved as the evaporated steam will not enter the blast furnace. Altogether the permeability of the blast furnace will be raised and higher PCI rates are possible. Figure 10 shows numerical simulation results comparing dense phase PCI using Oxycoal technology with dense phase PCI using Oxycoal technology and preheating of pulverized coal up to 200 °C. According to these results the additional increase of PCI rate using 200 °C preheated pulverized coal is minimum 16,8 g/s (or 3.1 %) and maximum 52.5 g/s (or 9.1 %).

Küttner built an industrial PC preheating plant for blast furnace No 1 at thyssenkrupp in Duisburg, Germany which is shown in figure 11. This PC preheating plant has been in operation for more than 13 years now. The PC preheating technology in combination with the Oxycoal technology is designed for maximum injection rates. This can be considered as the third step of optimizing existing PCI systems. But due to higher investment costs of a PC preheating plant compared to only-Oxycoal technology, the Return on Investment for PC preheating equipment is lower than for the Oxycoal technology.

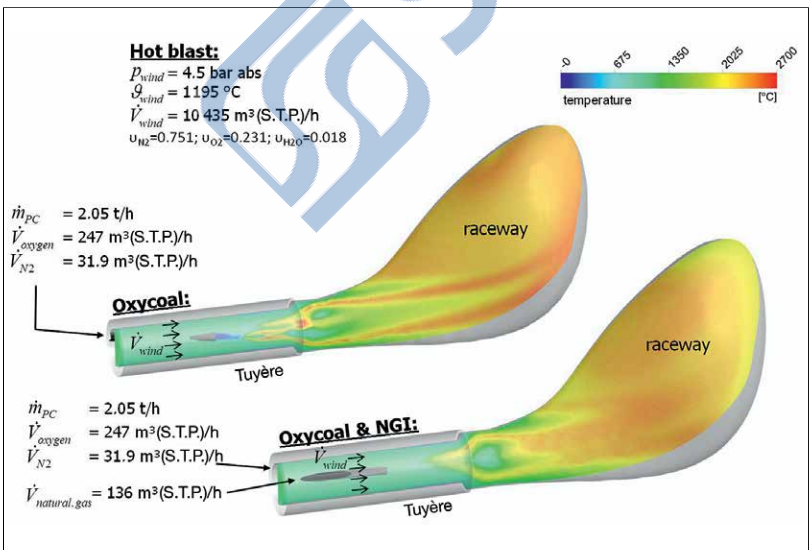
Pulverized coal is not the only auxiliary reducing agent used at the blast furnace. 10.9 % of all blast furnace operators uses natural gas (NG) [1] to reduce their coke rates and to improve their profitability. The profitability is mainly dependent on the costs of coke and the chosen auxiliary reducing agent. Some blast furnace operators in the world have the possibility to use either natural gas or pulverized coal as auxiliary reducing agent and some like to operate a combined injection of pulverized coal and natural gas. In this context combined injection means to inject natural gas and pulverized coal into all tuyères at the same time. This is possible but there are some limitations. The burning of injected natural gas is much faster than the gasification of injected coal. For this reason the oxygen of the hot blast is preferentially consumed by the burning of natural gas. But before natural gas is burned it has to be cracked. This costs energy which is supplied by the blast furnace process. The consequence is a local cooling of gas temperature in the tuyère and raceway and a lower raceway adiabatic flame temperature. In addition less free oxygen for coal gasification in the tuyère and raceway is available. Furthermore the endothermic Boudouard and heterogeneous water-gas reaction get more influence on coal gasification as hot steam and carbon dioxide are the products of burned natural gas. As a consequence the high temperature level in the tuyère and raceway is additionally lowered. Altogether natural gas injection has a negative influence on fast and complete coal gasification of a combined PCI and NGI process which results in reduced PCI rates converted by the blast furnace process.

In order to quantify this influence two numerical simulations with our gas flow and PCI process model of the tuyère and the raceway [5] were performed. Here, dense phase PCI including Oxycoal technology and combined NGI and PCI including Oxycoal technology is compared. The combined injection process is simulated with two separate injection lances, one coaxial lance for dense phase PCI using the Oxycoal technology and one single lance for NGI. The volume of injected natural gas was chosen to 136 m³(S.T.P.)/h which is a relatively small amount. The results of the numerical simulation in Figure 12 show the gas temperature distribution within the tuyère and raceway, indicating the burning of injected pulverized coal and natural gas. A later ignition of injected pulverized coal using the combined

11

Küttner's PC preheating plant at BF No 1 in Duisburg-Schwelgern, Germany

Küttners Anlage zur Vorwärmung von Kohlenstaub am Hochofen 1 in Duisburg-Schwelgern, Deutschland



12

Simulation results from PCI including Oxycoal versus combined NGI and PCI including Oxycoal

Vergleich der Simulationsergebnisse von PCI inkl. Oxycoal mit kombiniertem PCI inkl. Oxycoal und Erdgaseinblasen

NGI and PCI incl. Oxycoal compared to using only PCI including Oxycoal can be seen. Additionally the gas temperatures in the tuyère and raceway of the only PCI including Oxycoal process are locally hotter than for the combined injection process. These results confirm that NGI has a negative influence on a fast and more complete coal gasification of combined injection of pulverized coal. Further evaluations of these two simulations concerning the amount of completely and not completely gasified coal particles are shown in figure 13 (reference Oxycoal).

These evaluation results show an increase of not converted coal particles of 21.7 g/s (from 184.6 g/s to 206.3 g/s) for the combined NGI and PCI process. As a consequence, the minimal decrease of PCI rate converted by the blast furnace process is 4.3 %. But it is likely that the injected amount of pulverized coal is gasified according to the ratio of completely and not completely gasified coal particles for combined NGI and PCI incl. Oxycoal shown in figure 13. From this it can be concluded that the maximal decrease of PCI rate converted by the blast furnace process is 11.7 %. Here, too, the truth is somewhere between the minimum and maximum decrease of PCI rate.

Related to an example blast furnace with a daily production of 10 315 t_{HM} and 40 tuyères the results in figure 13 show that a NGI rate of 12.64 m³ (S.T.P.)/t_{HM} causes a decrease of PCI rate between minimum 7.8 kg/t_{HM} and maximum 19.1 kg/t_{HM} for combined NGI and PCI including Oxycoal process. Additionally it can be assumed that the exchange rate coke/coal is about 0.85 kg_{coke}/kg_{coal} and the exchange rate coke/natural gas is about 0.8 kg_{coke}/m³ $(S.T.P.)_{naturalgas}$. The outcome of this is that possible coke rate reduction by the use of high auxiliary reducing agent injection rates is slightly higher using only PCI including Oxycoal technology than using combined NGI and PCI including Oxycoal technology. Concerning the profitability of the fuel consumption of the blast furnace 1 m³ (S.T.P.) of natural gas needs to be cheaper than between 1.52 kg of pulverized coal (minimal decrease of PCI-rate caused by NGI) and 0.62 kg of pulverized coal (maximal decrease of PCI-rate caused be NGI) to become economically interesting.

Conclusion

Pulverized coal is the most used and in many cases most economic auxiliary reducing agent for the blast furnace. The more PCI rate converted in the blast furnace the better are the cost savings of blast furnace fuel consumption. In order to achieve high PCI rates it is necessary to ensure a fast coal gasification within the tuyère and raceway, as complete as possible; otherwise, it could negatively affect the permeability of the blast furnace. For the decision which PCI technology or which possible PCI optimization strategy should be used it is necessary to forecast the performance of the desired PCI technology and its effect on the blast furnace process. For this purpose Küttner uses its own gas flow and PCI process model of the tuyère and the raceway of the blast furnace [5]. The first step of optimizing existing PCI systems is to reduce the transport and injection gas to a minimum. From this follows that existing dilute phase PCI systems should be changed to dense phase PCI systems. The second step of optimizing existing PCI systems is to improve and accelerate the coal gasification within the tuyère and the raceway by using the Oxycoal technology. The third step of optimizing existing PCI systems is to use the PC preheating in combination with the Oxycoal technology which enables a further acceleration of pulverized coal gasification within the tuyère and the raceway of the blast furnace.

Another way to realize high PCI rates converted by the blast furnace process uses high oxygen enrichments of more than 30 to 35 % of the hot blast. In that case a simple dilute phase PCI system may be sufficient. But the profitability in doing so depends mainly on the costs of oxygen as a huge amount is needed. Also the combined injection of pulverized coal and natural gas may be interesting for blast furnace operators who have cheap natural gas. But it has to be considered that the possible coke rate reduction by the use of high auxiliary reducing agent injection rates is slightly higher using only PCI including Oxycoal technology than using combined NGI and PCI including Oxycoal technology.

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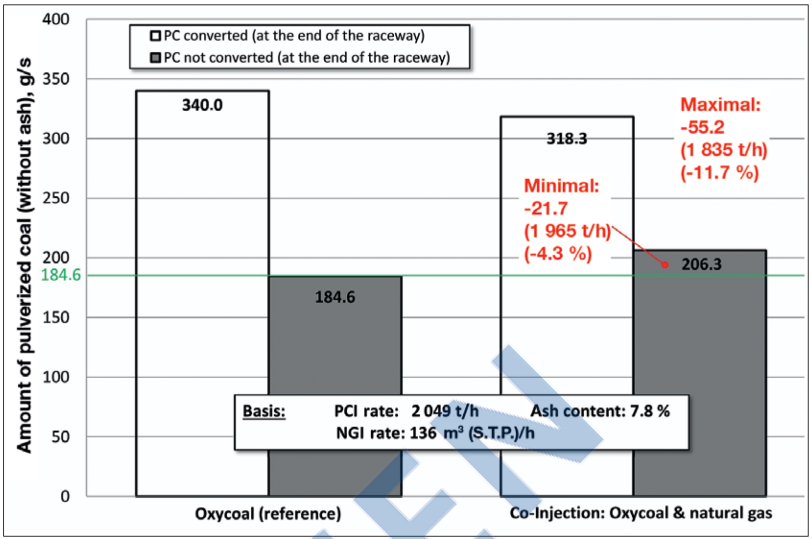

13

Degraded coal gasification from PCI including Oxycoal versus combined NGI and PCI including Oxycoal

Verschlechterte Kohlenstaubvergasung beim kombinierten PCI inkl. Oxycoal und Erdgaseinblasen, verglichen mit nur PCI inkl. Oxycoal

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