REDUCE CO_2 EMISSIONS AND COSTS IN BLAST FURNACE OPERATION WITH PULVERIZED COAL INJECTION*

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Abstract

The blast furnace process is the most important process to produce pig iron. The necessary process energy is mainly covered by coke. A significant measure to reduce the coke rate and with it the CO_2-emissions plus costs is pulverized coal injection (PCI) through the tuyeres into the blast furnace. This article is based on technical studies of Dr.- Ing. Robin Schott and Dr.- Ing. Franz Reufer comparisons and shows the cost effectiveness and the decrease of CO_2-emissions with the help of simplified energy balances for the operation using pulverized coal injection and the operation using the Oxycoal+ technology.

Keywords: Blast furnace; Pulverized coal injection (PCI); Oxycoal+ technology, decrease of CO_2-emissions; Reduction in costs.

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1 INTRODUCTION

1.1 PCI System

PCI is a complex system with several equipment. Normally, the first step is "coal grinding and drying" according to Figure 1.

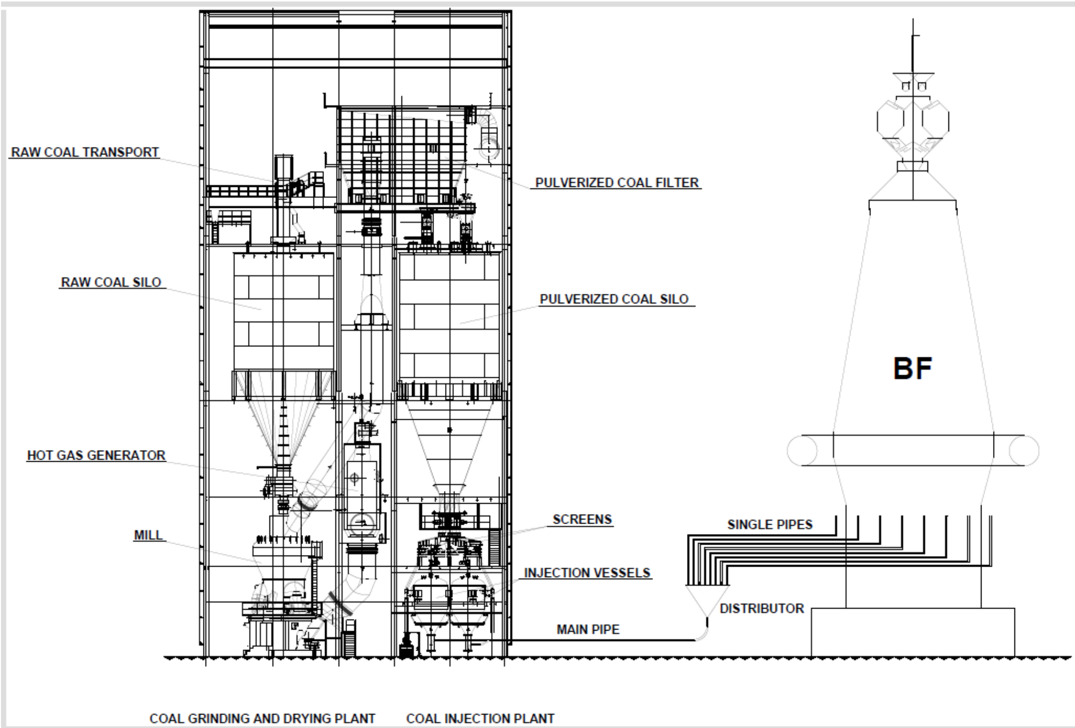

Figure 1. Coal grinding / drying and PCI plant with main pipe system.

The injection system and it's the philosophy is an important point as can be seen in Figures 2, 3, 4 and 5.

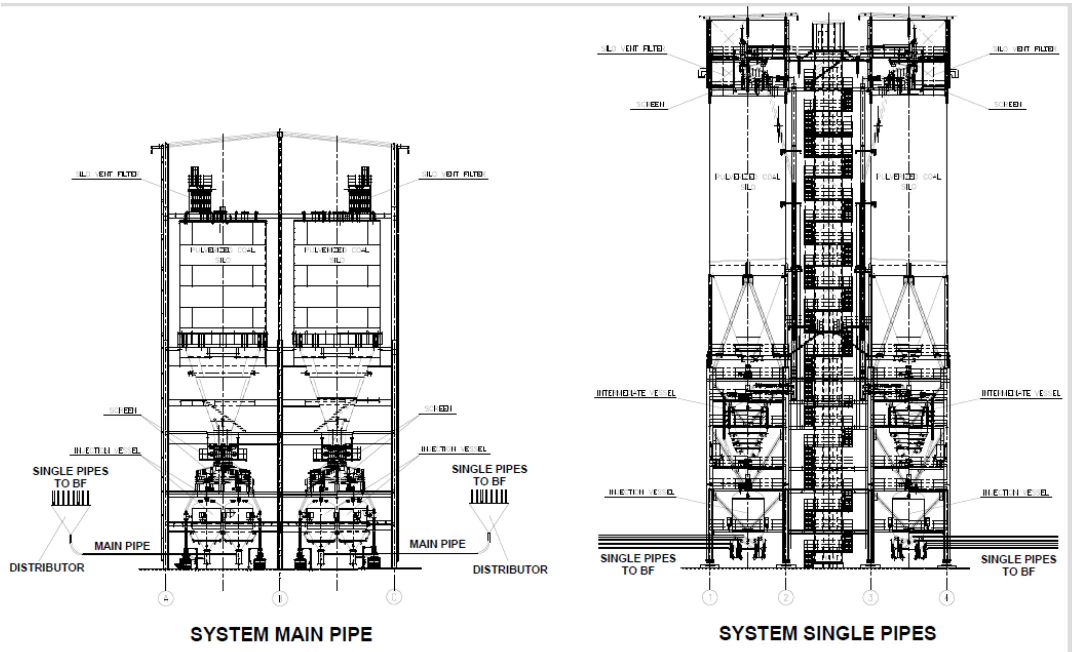

Figure 2. System of coal injection plants.

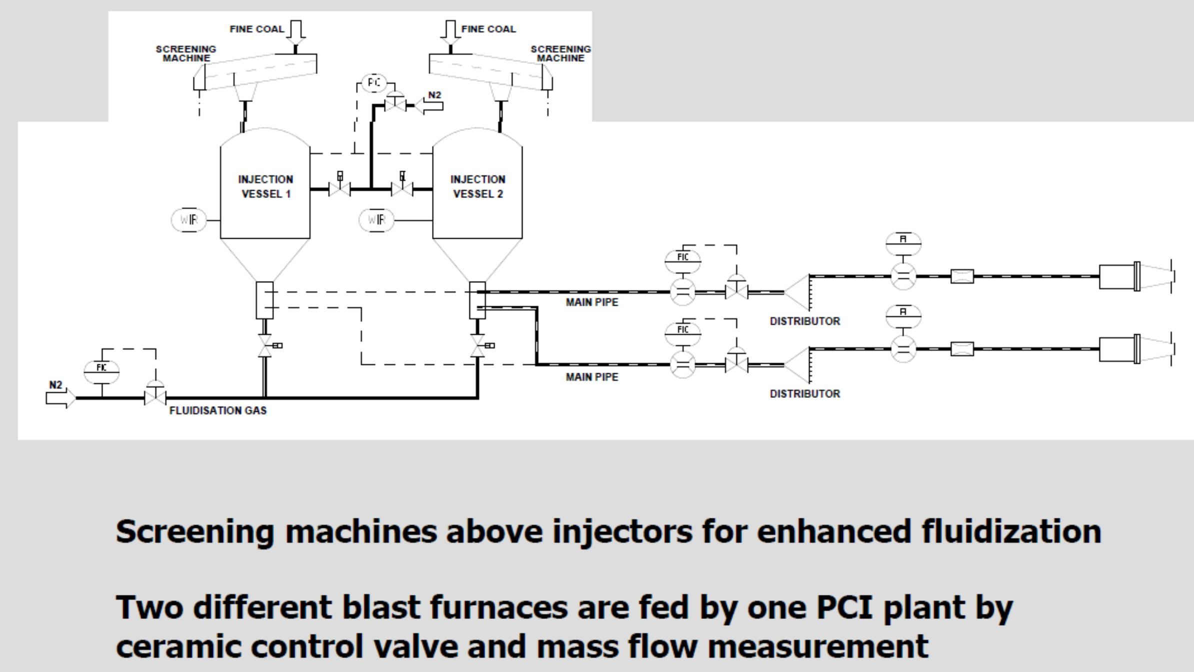

Figure 3. Philosophy of injection: Main pipe system.

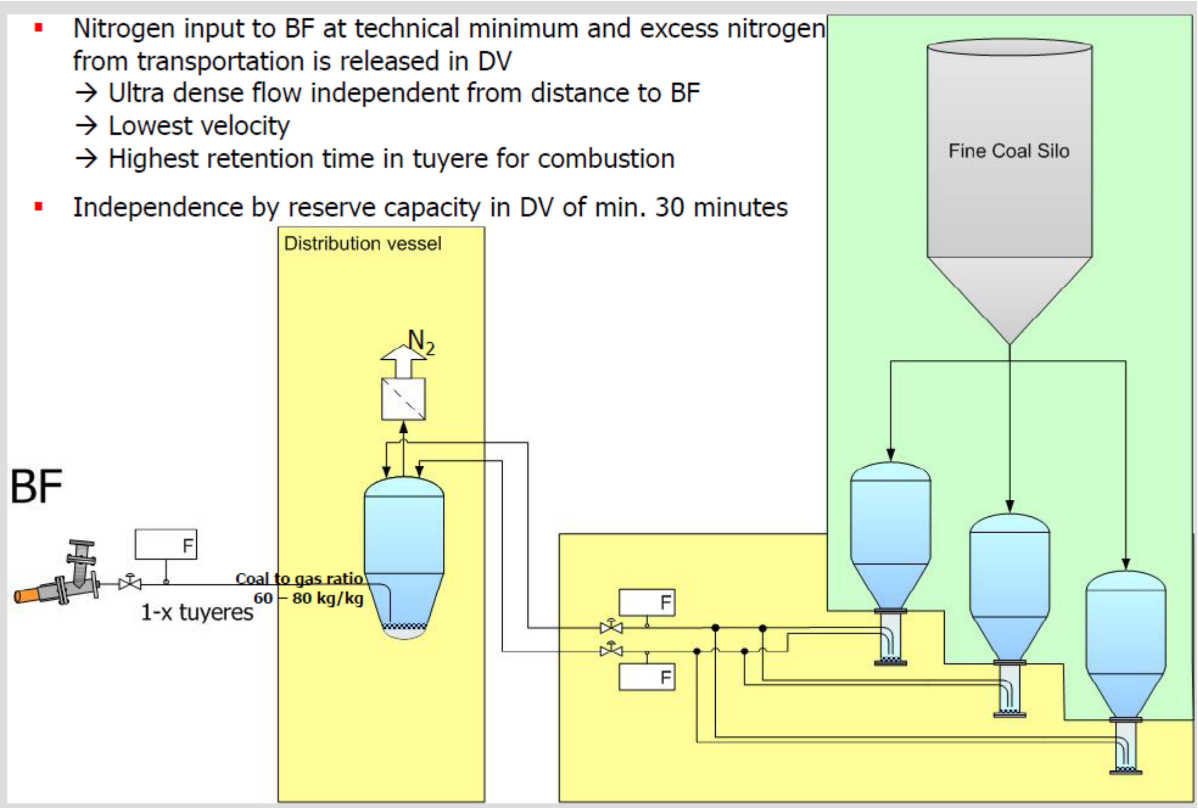

Figure 4. PCI+® set up with distributor vessel and single line control.

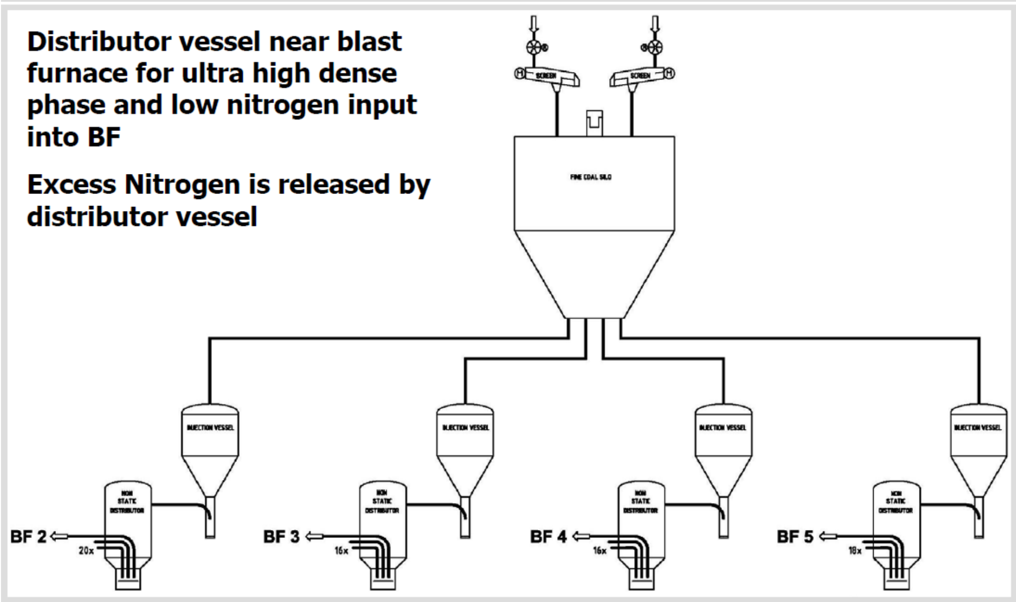

Figure 5. System with distributor vessel (E.S.C.H. type).

1.2 Injection of Pulverized Coal into the Blast Furnace

A pulverized coal injection system with Oxycoal+ technology is presented in Fig. 6. In this process the pulverized coal is conveyed pneumatically in the dense phase with nitrogen as carrier gas, out of a pressurized injection vessel, and over longer distances into a distributor in the vicinity of the blast furnace. The delivery rate is detected via a mass flow measurement and adjusted via a ceramic regulating valve. In the distributor, the pulverized coal is uniformly split over multiple individual lines of the same length that run to each individual tuyere. This is where the pulverized coal is injected into the turbulence zone of the blast furnace through the tuyere. Iron oxide is reduced in the blast furnace, essentially by the reduction gases CO and H_2 via heterogeneous gas-solid reactions. When injecting pulverized coal into the blast furnace, to the extent possible all the pulverized coal must be transferred in the flight phase. Approx. 10-20 ms are available for this [1]. This is the time period from entry of the pulverized coal particles into the hot gas stream until the end of the turbulence zone (i.e. into the boundary area of the coke bed).

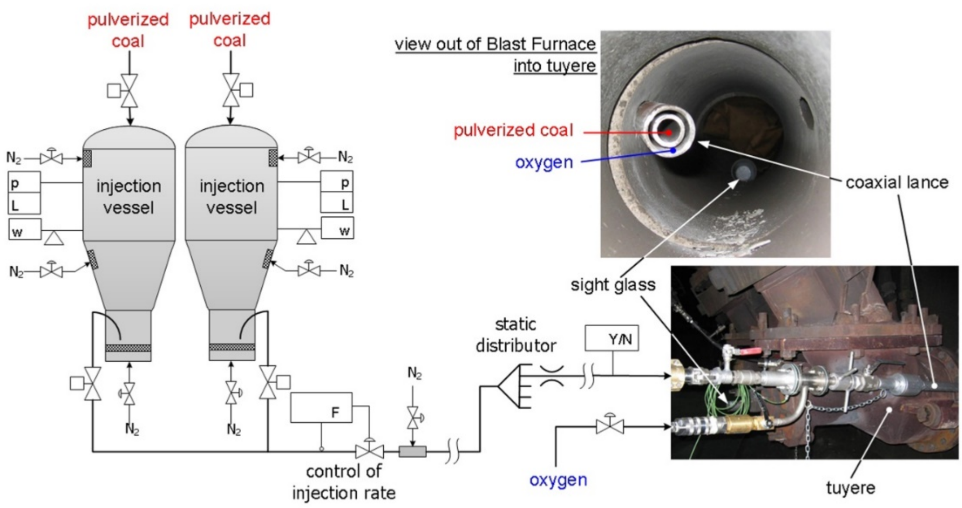

Figure 6. Pulverized coal injection system with Oxycoal+ technology.

In this short period of time the following reaction steps take place: First, the injected particles of pulverized coal are heated up to ignition temperature. This occurs through convective heat transfer from the hot blast and through radiant heat transfer from the tuyere wall, as well as through irradiation from the turbulence zone. In this regard, first the boundary areas of the injected jet of pulverized coal are heated up, since here a blending with the hot blast has not yet taken place, and the outer pulverized coal particles shield the inner pulverized coal particles against radiation [1]. Depending on the temperature achieved, first the residual surface moisture of the pulverized coal is evaporated. Then the pyrolysis of the heated pulverized coal starts, wherein the pyrolysis gases are combusted to CO_2 and H_2O due to the speed of the gas-gas reactions with the oxygen of the hot blast. The reaction heats occurring through these processes help other heat-up procedures run faster. The oxygen that is still present in the oxygen and steam of the hot blast, as well the combustion products CO_2 and H_2O, are gasification agents for the semicoke (carbon skeleton remaining after pyrolysis), which is now gasified depending on the temperature [1]. CO_2, H_2O, CO and H_2 are formed as reaction products, whereby CO_2 and H_2O disassociate depending on the temperature. Because the injected pulverized coal is not ideally distributed in the hot blast, but rather is present as "compact" jet, all processes occur in parallel, as soon as the ignition of the first pyrolysis gases starts. Escape of the pyrolysis gases from the coal particles transfers a pulse to the coal particles, whereby its movement direction can change, and overall a mixture of the injected pulverized coal with the hot blast occurs. However, a portion of the semicoke that is formed in the coke bed of the blast furnace is only converted here. This portion should be as small as possible. [1]

Injecting pulverized coal into the turbulence zone of the blast furnace via the tuyeres requires oxygen enrichment in the blast depending on the proportion of volatile matters of the coal for adjustment of the raceway temperature (RAFT) in the turbulence zone to the desired level. Without oxygen enrichment the raceway temperature would collapse due to the energies necessary for decomposition. Normally, the entire oxygen enrichment is fed into the cold blast upstream of the hot blast stoves. In this regard, the hot blast quantity is reduced by the quantity whose proportion of oxygen equals the quantity of oxygen enrichment. Otherwise, if the hot blast quantity is maintained, with addition of oxygen a capacity increase of the blast furnace would occur.

The limit for injection of pulverized coal is the beginning of incomplete conversion of the pulverized coal in the lower furnace. This becomes noticeable when semicoke appears from non-converted pulverized coal in the top gas dust and/or so-called "bird nest" zones occur (these are fine coal deposits in the edge zones of the dead man). If these "bird nest zones" cannot be gasified fast enough due to the lower partial pressure of the gasification agents here, this can cause a fault in the gas flow through the discharge column in the blast furnace. Excessive pressure loss that can no longer be compensated by the cold blast blowers and a deflection of the raceway into the edge zones of the blast furnace above the tuyeres are the consequence. At the same time the fluid drainage of dripping iron and slag is disturbed. [1]

The objective when injecting pulverized coal into the turbulence zone of the blast furnace is to replace as much "expensive" coke as possible with the "cheaper" substitute fuel, coal, at the same overall energy consumption of the blast furnace.

Injection rates from 160-180 kg/tHM at a total fuel consumption of below 500 kg/tHM can be considered as the state of the technology today.

1.3 Optimized use of Coal as Substitute Fuel in the Blast Furnace Process

The OXYCOAL+ technology is a further development of the pulverized coal injection technology. With this technology a portion of the oxygen necessary for enrichment of the blast is directly injected together with the pulverized coal into the tuyeres of the blast furnace via coaxial lances. A coaxial lance essentially consists of two straight pipes, one inserted and centered into the other; the pulverized coal is conveyed through the inner pipe with nitrogen as carrier gas and the oxygen is conveyed in the coaxial gap between the inner pipe and outer pipe. The important thing is that the oxygen must only come into contact with the pulverized coal in the hot blast stream in the tuyere.
Directly after the "cold" oxygen exits the coaxial lance there is no spontaneous mixing of the hot blast with the cold oxygen, because the viscosities that are dependent on the temperature (blast: $5.36\text{x}10^{-5}$ Pas, oxygen: $2.66\text{x}10^{-5}$ Pas) vary significantly. In this manner the jet of pulverized coal is surrounded with an oxygen sheath. It follows that the partial oxygen pressure is high in the direct vicinity of the pulverized coal particles in the boundary area of the jet of pulverized coal that is important for ignition. The result is an accelerated conversion speed of the injected pulverized coal [1]. Moreover the "sheathing" of the grains of pulverized coal with oxygen causes a lowering of the ignition temperature of the injection coal, i.e. an improvement of the local ignition conditions, whereby the start time of the conversion of the pulverized coal is shortened [1]. The conversion of injection coal already begins within the tuyere after ignition. An accompanying aspect is that a temperature increase in the tuyeres can be expected.
Figure 7 shows four photos that were taken through the inspection glass of tuyere of blast furnace that Küttner equipped with the dense phase and Oxycoal+ technology. This inspection glass is arranged in such a way that a view into the raceway in front of the tuyere of the blast furnace is possible. The photos on the left side show the pulverized coal injected into the tuyere at an injection rate of 800 kg/h (top left) and at an injection rate of 2000 kg/h (bottom left). In both photos a black cloud of pulverized coal that has not yet ignited in the tuyere is easy to see. On the right side, two photos are presented that show the same tuyere at the same injection rate and for which in addition 280 Nm³/h oxygen is injected with the aid of the Oxycoal+ technology. The combustion of the volatile components evaporating from the injection coal directly on the tip of the lance after entry into the hot blast stream can clearly be seen. This means that the injected pulverized coal already ignites in the tuyere and carbon conversion starts. When using the Oxycoal+ technology in the tuyere, temperatures higher than 2400°C can occur [1]. In dense phase operation, and with oxygen enrichment of the hot blast, the injected pulverized coal does not ignite in the tuyere, but it only combusts/gasifies in the raceway. As Fig. 7 shows in the photos on the left, the ignition temperature of the coal jet also in the boundary areas on the approx. 300 mm long path within the tuyere from the tip of the lance until into the raceway is not achieved.

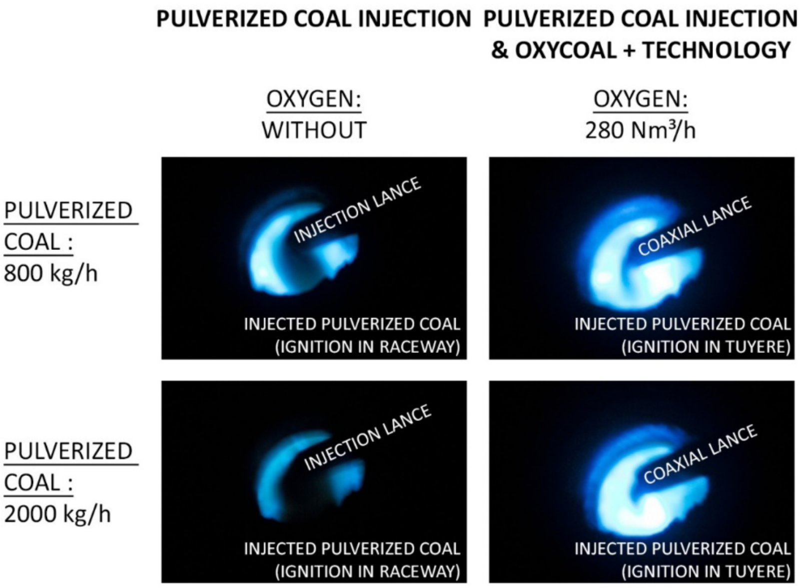

Figure 7. Influence of the Oxycoal+ technology on the conversion of the injected pulverised coal**.**

Overall for the Oxycoal+ technology less time is needed for carbon conversion due to the earlier onset of ignition of the pulverized coal. Thus an additional increase in the injection rate can be achieved with accompanying substitution of coke through the additionally injected pulverized coal. Experiences of our customers and our own calculations show that with the Oxycoal+ technology, the injection quantity can be increased by approx. 10 % relative to the "conventional" injection technology at conditions which are otherwise the same.

1.4 Main Parameter for fast Heating up and a high Conversion rate of Pulverized Coal

The main target to achieve this is to maximize the retention time in the tuyere. Here the speed of the injected coal has to be reduced to the minimum.
The coal combustion needs the reaction partners Carbon and Oxygen and a large surface that the reaction can take place at as many places simultaneously as possible. So a good mixing of coal and hot blast has to be achieved and in order to create a large surface the coal has to have a small mean diameter.
The ignition temperature of the coal can be influenced by the concentration of Oxygen in the surrounding gas. So the Oxygen level in coal cloud has to be maximized and the influence of the transport gas, which is Nitrogen, has to be minimized.
Last but not least the stability of the injection process is very important without pulsation and an even distribution to all tuyeres of the blast furnace.
Using a pulverized coal with a small mean diameter.
Using a blend of coals as the best compromise between ignition point and RAFT.
Using a pulverized coal with a low residual humidity (< 1 % surface humidity).
Minimizing the cold transport gas.
Producing a cloud of coal in the tuyere with a great surface.
Operation with a low lance outlet velocity.
Adjusting a high concentration of O_2 near the coal surface.
Adjusting a stable flame without pulsations.
Produce mixing energy between coal, oxygen and blast.

Adjusting the local and temporary constancy of coal flow also in short time intervals. Using ultra high density, ultra low velocity injection process.

1.5 Schematic Representation of Blast Furnace with PCI

Fig. 8 schematically shows the four different balancing groups of the blast furnace model, as well as the material flows fed into and discharged from the blast furnace. Balance group 1 includes the tuyere and the turbulence zone of the blast furnace. Balance group 2 comprises the lower furnace, including the reserve zone. Balance group 3 includes the entire top furnace and balance group 4 includes the entire blast furnace.

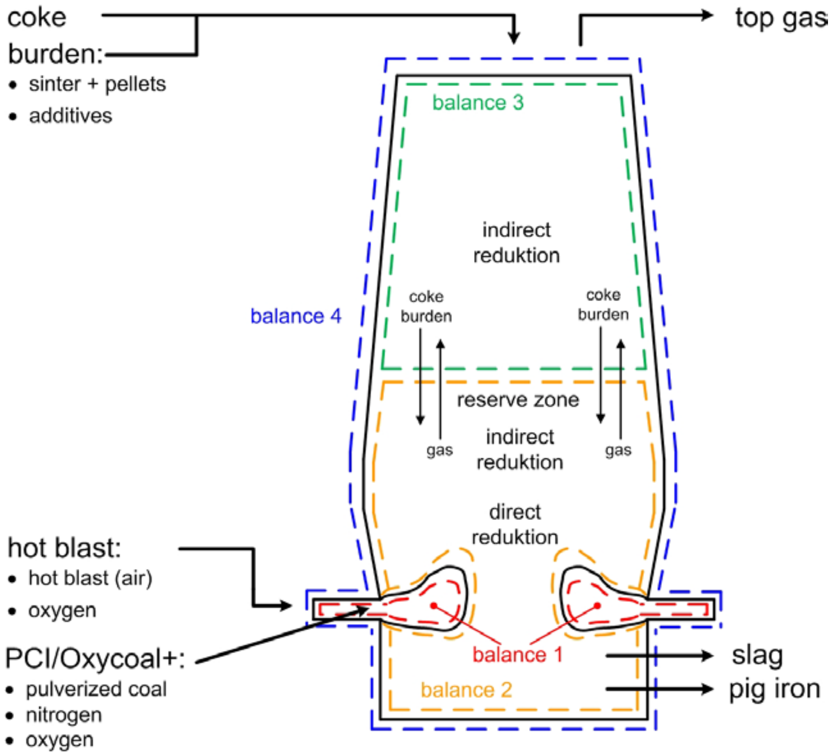

Figure 8. Schematic representation of the blast furnace model with PCI**.**

2 DEVELOPMENT

The table below (Table 1) compares three possible operating modes for a blast furnace on its respective coke consumption.
It is based on a blast furnace capacity of 10.000 t of pig iron per day, a blast capacity of 1.200 m³ (STP)/tHM and a blast temperature of 947 ºC.
As can be seen in the first column "coke only operation" 490,5 kg/tHM of dry coke are required which equals to an overall amount of 14,776.2 MJ/tHM in thermal and chemical energy via the burden, and 1,596.6 MJ/tHM via the hot blast.
The second column shows that with injection of pulverized coal into the raceway of the blast furnace via the tuyeres, a portion of the coke in the burden is replaced by injection coal. Now 296.2 kg/tHM of coke is supplied via the burden and 178.2 kg/tHM injected pulverized coal is supplied via the tuyeres. In addition 4.5 m³ (STP)/tHM nitrogen as transport gas is injected into the blast furnace via the tuyeres. The supplemental fuel through the tuyere requires oxygen enrichment in the blast of 46.3 m³ (STP)/tHM to maintain the raceway temperature. In this case, merely

increasing the blast temperature to 1,200 °C, does not suffice. The required blast quantity is 900 m³ (STP)/tHM. Thus overall the tangible and chemical energy cited in Table 2 is supplied to and discharged from the blast furnace.
The third column refers to the Oxycoal+ technology the substitution of coke through pulverized coal can be further increased. Operational experience shows that, an approximately 10 % increase in the pulverized coal injection rate is assumed. In this regard 282.5 kg/tHM of coke are charged with the burden and 195 kg/tHM of pulverized coal are injected through the tuyeres. In addition 5.2 m³ (STP)/tHM nitrogen as transport gas and 20 m³ (STP)/tHM oxygen are injected into the blast furnace via the tuyeres. The hot blast must be enriched with 43.8 m³ (STP)/tHM oxygen. The higher oxygen supply of 63.8 m³(STP)/tHM as compared with 46.3 m³ (STP)/tHM is based on maintaining of the mathematical raceway temperature of 2,150 °C at the increased rate of pulverized coal injection. The blast quantity is 823 m³ (STP)/tHM at a blast temperature of 1200 °C. Thus, overall the thermal and chemical energy cited in Table 1 are supplied to and discharged from the blast furnace.

Table 1. Results of the blast furnace simulation calculations

Blast furnace 10,000 t_{HM}/d	**Coke-only operation**				**Injection of pulverized coal**				**Oxycoal+ technology**			
	Mass flow		temp.	Energy	Mass flow		temp.	Energy	Mass flow		temp.	Energy
	kg/t_{HM}	m³	°C	MJ/t_{HM}	kg/t_{HM}	m³	°C	MJ/t_{HM}	kg/t_{HM}	m³	°C	MJ/t_{HM}
Supply:												
Coke	490,5	-	15		296,2	-	15		282,5	-	15	
Burden:				14.776,2				8.930,5				8.517,6
Sinter + pellets	1.571,2	-	15		1.571,2	-	15		1.571,2	-	15	
Additives	10	-	15		10	-	15		10	-	15	
Blast furnace blast:												
Blast (air)	-	1.200	947	1.569,6	-	900	1.200	1.602,4	-	823	1.200	1.423,4
Supplemental oxygen	-	-	-		-	46,3	1.200		-	43,8	1.200	
Pulverized coal/ Oxycoal+:												
Pulverized coal	-	-	-		178,2	-	30		195	-	30	
Transport nitrogen	-	-	-	-	-	4,5	30	5.840	-	5,2	30	6.391
Oxygen	-	-	-		-	-	-		-	20	30	
Discharge:												
Pig iron	1.000	-	1.500	- 1.294,2	1.000	-	1.500	- 1.294,2	1.000	-	1.500	- 1.294,2
Slag	243,5	-	1.510	- 444,1	237,7	-	1.510	- 433,5	237,4	-	1.510	- 432,9
Top gas	-	1.726	110	- 5.111,6	-	1.521,5	110	- 5.199,7	-	1.479,3	110	- 5.144,6
Heat losses	-	-	-	- 550	-	-	-	- 550	-	-	-	- 550
Blast furnace process	-	-	-	- 8.945,9	-	-	-	- 8.895,5	-	-	-	- 8.910,3

In Table 2 the results of the efficiency increase of the reducing agent use on the blast furnace are cited. The results show that through installation of a pulverized coal injection system for a 10,000 tHM/d blast furnace occurs a significant reduction of CO_2 emissions and if the existing pulverized coal injection system is equipped with the Oxycoal+ technology, the efficiency of reducing agent use can be further increased. In this case there is an additional reduction of CO_2 emissions of 14.37 kg/tHM.

Table 2. Efficiency increase of the reducing agent use 1 year is assessed at 350 work days)

Blast furnace 10,000 tHM/d	**Coke-only operation versus injection of pulverised coal**	**Injection of pulverised coal versus Oxycoal+ technology**
Increase of the injection rate	178.2 kg/tHM (= 623,700 t/a)	16.8 kg/tHM (= 58,800 t/a)
Coke savings	194.3 kg/tHM (= 680,050 t/a)	13.7 kg/tHM (= 47,900 t/a)
CO2 emissions reduction (Mainly in the coking plant)	385.88 kg/tHM (= 1,350,580 t/a)	14.37 kg/tHM (= 50,295 t/a)
Increased oxygen consumption	46.3 m³ (STP)/t_{HM} (= 162.05 x 106 m³ (STP)/a)	17.5 m³ (STP)/ tHM (61.25 x 106 m³ (STP)/a)
Energy savings – hot blast	-32.8 MJ/tHM (= -114,800 GJ/a)	179,0 MJ/tHM (= 626,500 GJ/a)
Quantity reduction – hot blast	300 m³ (STP)/t_{HM} (= 1.05 x 109 m³ (STP)/a)	77,0 m³ (STP)/tHM (= 269.5 x 106 m³ (STP)/a)
Energy gain – top gas	88.1 MJ/t_{HM} (= 308,350 GJ/a)	-55.1 MJ/tHM (= -192,850 GJ/a)

3 CONCLUSION

Based on the technical studies of Dr.- Ing. Robin Schott and Dr.- Ing. Franz Reufer we can see that the increased efficiency of reducing agent use, blast furnace operating modes injection of pulverized coal and use of the Oxycoal+ technology, are compared with coke-only operation. To evaluate the efficiency of reducing agent use, at this point the carbon dioxide emissions and the costs are considered.
Reduction of coke use in the blast furnace results in a reduction of the carbon dioxide emissions mainly in the coking plant, because less coke must be produced. To quantify the CO_2 savings a carbon balance is created around the blast furnace and the coking plant in which the entire quantity of carbon carriers required for production of the specified quantity of pig iron is converted to CO_2. For calculation of the CO_2 savings the requirement of electrical energy for the additional oxygen enrichment and the reduced blast compaction were not taken into account.
The essential cost reducing lever is substitution of coke with injected coal, as compared with coke-only operation of the blast furnace. The reason for this is the significant price difference between coke and coal, delivered to the blast furnace. It must be considered that the cost situation differs for each blast furnace plant and depends on the economic situation.

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