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Development and application of a particle conversion model for the utilization of biochar in an electric arc furnace to substitute fossil coal

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A novel adaptation of a layer model for single-particle conversion is presented, explicitly accounting for diffusion effects and dynamic changes in particle structure (e.g. specific surface area, porosity, pore diameter) during conversion. The model has been parameterized using both literature data and new experimental results and is applied to both petrol coke as a reference and biochar under realistic EAF gas atmospheres (CO/CO_2 mixtures) and temperatures. This dual approach enables direct comparison and transferability of kinetic parameters across material classes. The research addresses a critical gap in the systematic evaluation of biochar for metallurgical use, by focusing on the conversion of coal particles under conditions typical for those applications. By establishing quantitative relationships among key material parameters (density, volatile content, specific surface area, pore size) and conversion kinetics, the study offers a rational basis for selecting and optimizing biochar for this industrial application. The findings provide guidelines for the production and pre-treatment of biochar tailored to EAF injection, supporting decarbonization strategies in steelmaking. The validated modelling framework can be extended to other high-temperature applications, facilitating the broader adoption of renewable carbon sources in the metallurgical sector.

KEYWORDS: EAF; BIOCHAR; SLAG FOAMING; PARTICLE CONVERSION; MODELLING.

INTRODUCTION AND BACKGROUND

The need to reduce CO_2 emissions from the metallurgical industry has led to increased research in this area in recent years. For example, extensive research has been conducted on the use of biochar as a substitute for coke or coal in the blast furnace process and upstream processes (sintering, coking), which has demonstrated the fundamental suitability of biochar as a substitute for coal/coke [1, 2, 3, 4]. However, current projects in the steel industry are primarily focused on converting blast furnaces to electric arc furnaces (EAF) and/or the use of hydrogen as an energy source and reducing agent.

The use of biochar in the EAF has been investigated, amongst other things, in two major EU-wide research projects [5, 6]. In modern EAFs, the proportion of energy input from fossil fuels accounts for over 40% of the total energy input.

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EAFs typically use fossil carbon materials—most commonly petroleum coke or anthracite—to create slag foaming in the refining phase. These materials account for approximately 5-10% of total CO_2 emissions in EAF steel production. Substituting these materials with biogenic, carbon-neutral alternatives could avoid 30-60 kg CO_2 per ton of steel.

Apart from the use of charge coal during the charging process of the EAF the main application of petroleum coke or anthracite in the EAF is the use as injection coal for foam slag formation. The combined injection of O_2 and C via working lances or injectors into the interface between the melt and the slag leads to the formation of CO bubbles. Furthermore, the C in the coke reacts with the iron oxide in the slag and reduces it to metallic Fe, also forming CO bubbles. These cause the slag to foam. In the EAF, the foamed slag serves the following purposes:

- Absorption of impurities from the scrap
- Increased energy transfer efficiency: the foam slag shields the arcs, reducing energy losses through the water-cooled furnace walls and ceiling
- Stabilisation of the arcs and reduction of noise emissions

Biochar has emerged as a promising candidate to substitute fossil carbon carriers due to its high carbon content and potential for renewable sourcing. However, its behaviour during injection, heating, gasification and slag-foaming differs strongly from fossil coals. Understanding these differences requires a comprehensive approach that includes systematic experimental decomposition tests carried out under controlled atmospheres, as well as detailed modelling of particle-scale conversion kinetics. Furthermore, it is essential to validate the findings under industrial EAF conditions to ensure practical applicability.

OBJECTIVES

The primary objective is to enable the substitution of fossil-based injection coals with biogenic coals in EAF operation by establishing robust criteria for material suitability, especially concerning the ability of the coal to produce foaming slag. This is paramount for EAF operation, because slag foaming increases the efficiency of the EAF by its thermally insulating properties and enables slag separation at the end of each heat. The approach models the conditions in an EAF using CFD simulations und the thermal and chemical conversion of individual coal particles employing a layer-based model tailored to EAF conditions. The model parameters are calibrated using experimental data from laboratory-scale decomposition tests of biochar as well as petrol coke. The model is then applied to calculate the conversion of biochar and petrol coke under EAF conditions (gas atmosphere and temperatures) and assesses the performance of biochar regarding slag foaming.

METHODOLOGY

General approach

1. The investigations were carried out in stages:
2. Steady-state and transient CFD simulations of the expected heating characteristics and environmental conditions of the biochar upon injection into the EAF to determine the framework conditions for biochar conversion in the EAF, in comparison to the behaviour of the petroleum coke used to date.
3. Detailed single-particle simulations of biochar conversion, considering the temperature profiles and gas compositions derived from step 1, as well as a comparison of the results to the conversion behaviour of currently used coke as a reference process.
4. Conducting a sensitivity analysis to examine the relevant factors influencing biochar conversion regarding the parameters of chemical composition and content of volatile components, particle size, specific surface area, pore diameter and particle density (or porosity).
5. Overall assessment of the results, considering relevant influencing factors regarding biochar properties in relation to foam slag formation capacity (CO release over time), as well as the definition of relevant biochar compositions in this regard.
6. Testing the findings of the investigations in trials with tailored biochar at the EAF of Marienhütte.

CFD simulations of the expected environmental conditions in an EAF

To investigate the conditions for the injection of fossil coal and biochar into the EAF at the Marienhütte during

the refining phase, the following CFD simulations were carried out:

Steady-state gas-phase simulations for the side wall burner (Oxygen injection with enveloping CH_4-flame) without considering blown coal, molten steel and foaming slag → this simulation allows for an assessment of the unmodified side wall burner and the burn-out under these conditions

- Steady-state multi-phase simulations for fossil coal (petroleum coke) and biochar when injected into the EAF, considering the molten steel (without foaming slag)→ this simulation allows the situation to be assessed approximately before primary foaming begins
- Transient multi-phase simulations for fossil coal (petroleum coke) and biochar when injected into the EAF, considering the foaming slag and the molten steel → the simulations carried out under this heading enable an assessment of the flow and distribution of the foamed slag during the refining phase, once the slag has already been foamed.

Detailed single-particle simulations of biochar conversion

The calculations presented here were carried out using a computational model for the thermal conversion (drying, pyrolysis, combustion) of individual fuel particles, developed by BIOS (shell model/layer model, [7]).

In the basic model, a fuel particle is treated either as a spherical or cylindrical particle. It is divided into five layers, each corresponding to a stage in the combustion process (wet fuel, dry fuel, partially pyrolysed fuel, charcoal, ash, see figure 1).

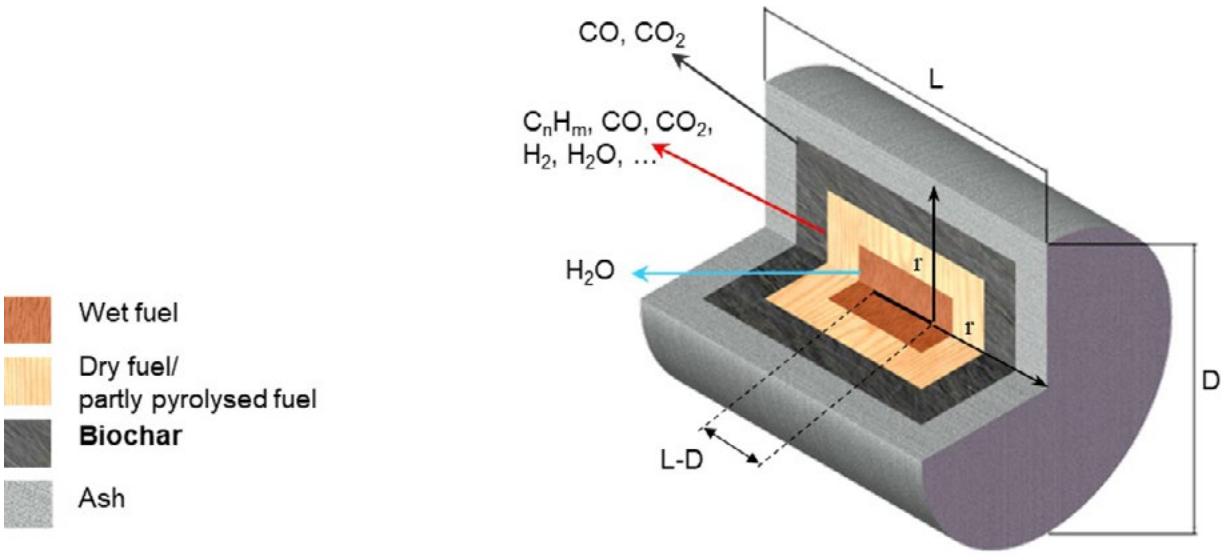

Fig.1 - Layers considered in the basic layer model.

The interfaces between the individual shells correspond to the reaction fronts of the ongoing processes (drying, pyrolysis, carbon burnout/carbon gasification), which move towards the centre of the particle during combustion.

This model can describe the thermal conversion of the particles: internal temperature gradients, mass losses of the particles, and time-dependent changes in particle size and density.

For use in this project, the layer model was modified to represent the behaviour of the coal particles under consideration. The layers for drying and pyrolysis were de-activated (particles initialised as coal). The proportions of H and O present in the coal, as determined by analysis, are assigned to volatile intermediate products of carbonisation. The central focus of the modelling is the reaction of the coal with CO_2, as in the EAF (based on equilibrium calculations) a gas atmosphere of approx. 85 vol% CO and 15

vol% CO_2 is expected, with other gases occurring only in small quantities.

For this conversion reaction ($C + CO_2 \rightarrow 2CO$), a volumetric conversion of the coal in the region reached by the CO_2 was assumed since the reaction rates are generally slower than, for example, those involved in the combustion of coal with O_2, and (depending on the prevailing temperatures, particle sizes and CO_2 supply) the reactant CO_2 can diffuse into the coal particles due to their porous structure. These effects were considered in the kinetic calculations.

The kinetics of the conversion reactions were analysed applying a comprehensive literature research and were further adapted and validated by experimental data, derived from particle conversion tests with petroleum coke and biochar under various temperatures and gas atmospheres like those in an EAF.

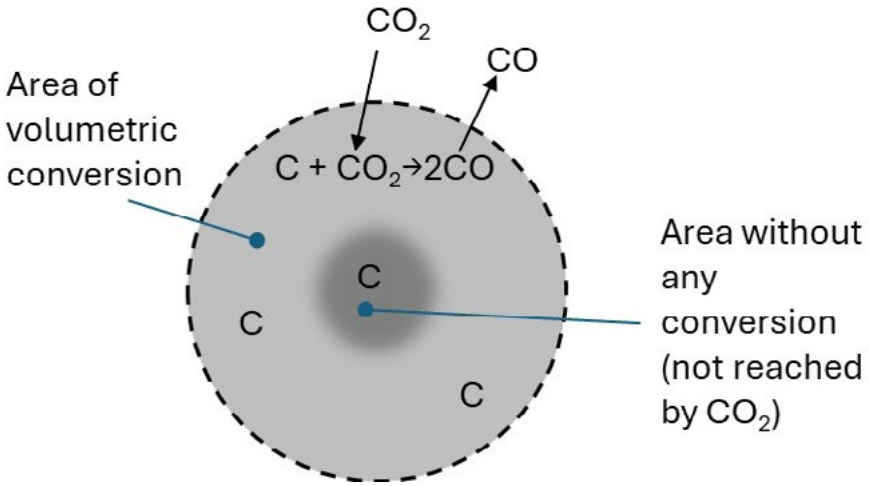

Fig.2 - Schematic conversion of coal/biochar particles with CO_2.

The adapted and validated model was used to evaluate the conversion behaviour of biochar and petroleum coke as a reference under EAF conditions (derived from the CFD simulations performed).

Sensitivity analysis to examine the relevant factors influencing petroleum coke and biochar conversion in an EAF and definition of relevant biochar characteristics relevant for slag foaming

The adapted and validated layer model was used to evaluate the influence of relevant properties of the carbon carriers such as density, particle size, specific surface area or porosity on the behaviour of biochar under EAF conditions compared to petroleum coke as a reference. Based on the findings, the relevant parameters for biochar suitable as injection coal for slag foaming have been derived.

Industrial trials with tailored biochar in the EAF at Marienhütte

Biochar tailored to the parameters defined was then used in trials in the EAF at Marienhütte, where 100% petroleum coke was substituted by tailored biochar for several heats. The performance in terms of coal consumption, metallic yield, slag foaming level and FeO-content in slag was recorded and compared with the data from reference heats produced before and after the trials.

The results of the work described are shown in the following sections.

RESULTS

Definition of environmental conditions in an EAF for injected carbon carriers based on CFD simulations

The detailed results of the CFD simulations are beyond the scope of this paper, so only some selected results relevant for the further use in the particle conversion calculations are presented here. The simulations were performed with the standard blowing coke currently used at Marienhütte and milled biochar made from hardwood. The milling of the biochar was performed based on findings from earlier pre-tests with unmilled hardwood bio-

char (d(50) > 1 mm) that showed only slight foaming and unused biochar particles swimming on the molten, hardly foamed slag. The milled biochar featured a slightly higher particle size (d(50) approx. 0.46 mm) than the petroleum coke used (d(50) approx 0.39 mm).

The chemical composition of the petroleum coke and hardwood biochar were derived from wet chemical analysis. The main difference between the two carbon carriers were the C-content (approx. 97.6 % of dry weight, ash free for the petroleum coke compared to approx. 87.3% for the biochar and the amount of volatiles (<1 % of dry weight for the petroleum coke compared to approx. 15 % of dry weight for the biochar).

The results show that most of the blown coal/biochar particles reach the surface of the melt (approximately 99% of the mass for both biochar and fossil coal). Only the lightest particles are carried upwards by the gas flow. The particles of both types of blown coal have an average residence time of approximately 0.05 s until they get into contact with the melt. The particles are heated as they travel from the injector to the surface of the melt, although a wide variation in the values can be observed (typical range between 210 and 350°C). Once in the melt, the particles are considered to stay in the melt/the foaming slag till they are fully decomposed.

From the simulations carried out, the average ambient conditions and particle temperatures along the residence time of the injection coal particles for both types of injection coal can be derived from the evaluations conducted along the particle trajectories.

They were used as boundary conditions for the single-particle simulations described below. This allows the differences between fossil coal (petroleum coke) and biochar in terms of the behaviour of the particles in the EAF at the start of the refining phase and during the refining phase to be examined and evaluated in detail.

Development of a single-particle conversion model for injection coal in the EAF

Several relevant studies have been performed regarding the reaction kinetics of injection coal in an EAF [8, 9,10]. Based on a thorough evaluation of the relevant reaction C+ CO_2 → 2 CO, the following findings could be derived in [8]:

The reaction rate depends on the available surface area of the carbon. The specific surface area is particularly relevant here, as CO_2 can diffuse into the interior of the particles through the porous structure of the carbon. The composition of the gas surrounding the carbon particles has a major influence on the reaction rate. In the presence of CO, the reaction is significantly slowed down, as CO is adsorbed onto the surface of the carbon, thereby reducing the surface area available for the reaction with CO_2. This effect varies in intensity for different types of carbon (differences were investigated between metallurgical coke, coconut-based biochar and graphite), as the structure of the carbon matrix differs (i.e. it is more or less crystalline in nature).

Consequently, the reaction rate is influenced by the following parameters of the coal/biochar:

- Specific surface area: linear dependence; however, a small pore size combined with a large specific surface area limits the reaction rate (diffusion limitation, see below)
- Temperature: high temperatures significantly accelerate the reaction rate
- CO_2 concentration: a higher CO_2 concentration increases the reaction rate
- CO concentration: a higher CO reduces the reaction rate; the lower the temperature, the greater the reduction

The linear dependence of the specific surface area on the reaction rate means that the model can be applied to different types of coal (fossil coal and biochar). The above correlations are valid if full pore diffusion is possible. However, at higher temperatures, with larger particle diameters and faster reaction rates, this is no longer the case, and the decomposition reaction takes place only within a specific region of the particle (as described in [9]). In the limiting case, a sharply defined reaction front forms at the particle surface. To determine the scope of validity of the kinetics and to account for a limitation due to diffusion in the model, an approach according to [9] was implemented and the results compared with data from the same reference [9]. This showed that neglecting diffusion leads to a distortion of the results. The influence of diffusion increases with increasing temperature (the higher the

temperature, the more diffusion slows down the reaction rate) but decreases with increasing pore diameter and porosity (the large the pore size and the larger the porosity, the higher the reaction rate).

The adaptations of the model so far were based solely on data from literature and did not consider changes in the coal's parameters as decomposition progresses.

It therefore had to be verified in the next step by comparing it with measurement data from laboratory tests carried out specifically for this purpose.

Within the lab-tests, different carbon carriers (petroleum coke and hardwood biochar) were exposed to various atmospheres (CO/CO_2 mixtures, pure CO_2 and pure N) in a laboratory reactor at different temperatures (between 900 °C and 1100 °C). Care was taken to ensure good flow-through of the sample and consistent particle sizes. The gas concentrations resulting from the decomposition were measured, and the mass loss of the sample over time was calculated from these. The mass loss of the sample over the entire experiment was determined gravimetrically as a reference.

Furthermore, based on database values for biochar and analyses of samples from the decomposition tests (residues from test runs under pyrolysis conditions, or from degradation tests carried out specifically for this purpose), correlations were derived for the changes in the structure of the various coals during decomposition, which were considered in the layer model.

The values for specific surface area and pore size in the partially decomposed samples show a linear increase in specific surface area as decomposition progresses, accompanied by a decrease in pore size. The pore size decreases exponentially with increasing specific surface area, as analyses of different biochar and petroleum coke samples show (see figure 3). Both correlations were implemented in the layer model and used for all coals considered (petroleum coke and biochar).

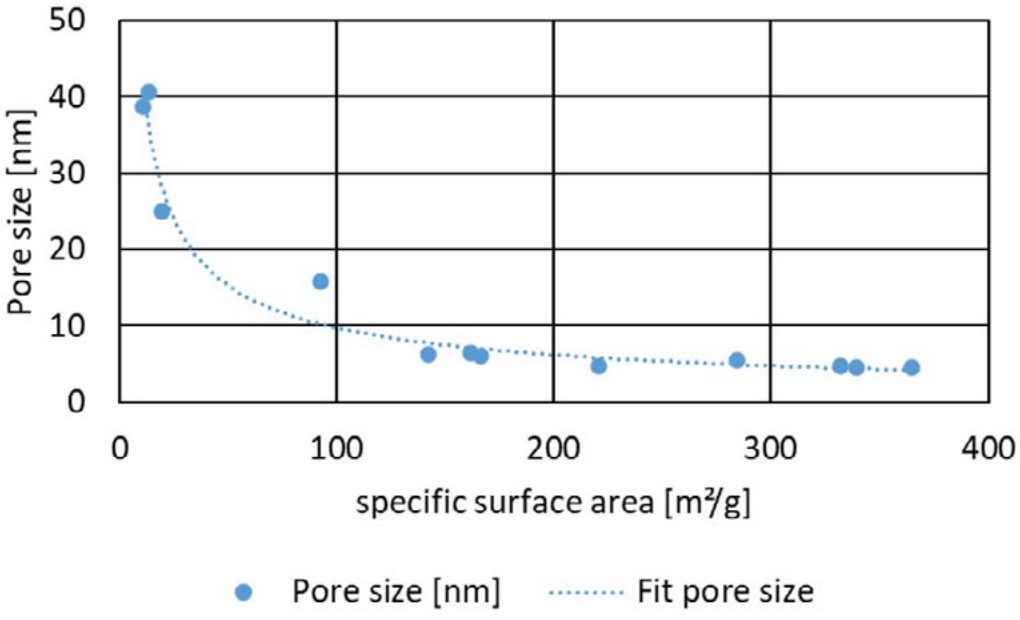

Fig.3 - Correlation between specific surface area and pore size of different carbon carriers.

The comparison of the results of the decomposition tests and the results gained with the adapted layer model showed that, although the trends visible in the results of the decomposition tests can be forecasted by the given kinetics, parameter adjustments are necessary to describe the decomposition of the individual coal types accurately. Therefore, kinetic parameters were determined from the decomposition curves derived from the experiments.

Figure 4 shows the mass conversion over time for various CO_2/CO atmospheres and temperatures in comparison to the corresponding experimental results for biochar from hardwood (left) and petrol coke (right). These data were used to optimise the kinetic parameters; the "Layermodel" - curves employ the final parameter set for each type of coal that were used for the simulation of the decomposition of petroleum coke and biochar particles in the EAF.

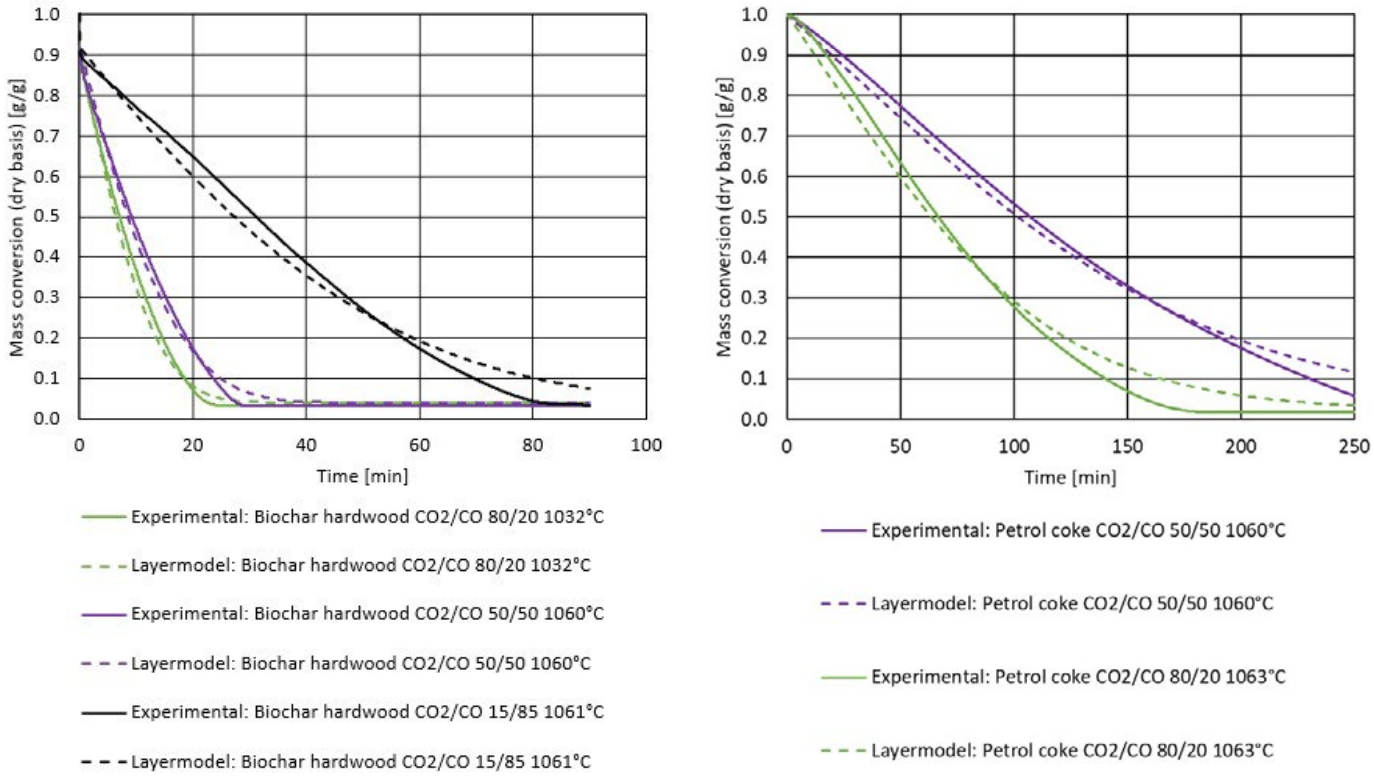

Fig.4 - Mass conversion over time (calculated on dry basis) for the conversion of biochar from hardwood (left) and petrol coke (right). The solid lines represent experimental results from lab-scale reactor tests, the dashed lines are results from layer model calculations with an optimised set of kinetic parameters.
Explanations: experimental ... mass conversion based on laboratory experiments; layermodel ... mass conversion based on calculations using the adapted layer model; CO_2/CO xx/yy ... gas composition in vol% (xx: CO_2, yy: CO)

Results of single-particle simulations under EAF conditions and sensitivity analysis

Based on the CFD simulations carried out for the EAF (for biochar and fossil coal, see above), the environmental conditions of the injected coal particles were determined along their path from entry into the EAF until they strike the boundary layer between the slag and the molten bath (or until they exit the area relevant to the foam slag).

From this, profiles were extracted for the temperatures in the vicinity of the particles (temperature of the surrounding medium or radiation temperature), the relative velocity of the particles with respect to the surrounding medium, and the prevailing gas composition in the vicinity of the particles. These profiles were used in conjunction with the adapted and extended layer model (including the kinetics derived from the decomposition tests) for single-particle calculations, including sensitivity analyses. This allows relevant factors influencing the decomposition rate—such as particle density, diameter, specific surface area and pore size, as well as volatile content—to be investigated.

It is assumed that, upon their first direct contact with slag, the coal particles react immediately with it, and a gas bubble forms around each particle. The gas composition within the bubbles is approximated to correspond to the equilibrium composition in the EAF (due to the good mix-

ing in the EAF). The profiles were therefore maintained at equilibrium conditions for the remainder of the time (duration of the refining phase: 6 minutes).

The calculations were performed with data for petroleum coke and three different types of biochar from hardwood (see table 1).

Under the conditions prevailing in the EAF, the decomposition of the coal particles essentially only begins after they strike the interface between the slag and the molten bath. The decomposition during the short period of time till it hits the surface of the molten bath (along the profiles determined from the CFD simulations) is mainly limited to the decomposition of volatiles (pyrolysis). Therefore, the number of volatiles is almost immediately released (shown by the almost immediate mass loss at the beginning in figure 5).

The subsequent decomposition of the particles investigated takes between 2.5 and 6 minutes (depending on the particle properties, see figure 5). Selected results of comprehensive sensitivity analyses performed are shown in figure 6. Biochars that feature a similar decomposition time as the reference petroleum coke (4 minutes) shall show a similar foaming performance. The decomposition time is a key factor for successful slag foaming, and the test results on the EAF (see below) confirm this interpretation.

Tab.1 - Carbon carriers evaluated in the single particle simulations.
Explanations: Skeleton density ... density of the particle without voids and pores; Envelope density ... density of the particle including voids and pores; The envelope density of Hardwood 2 was not explicitly measured. Due to the similar skeleton density, a similar envelope density was assumed; void fraction ... the void fraction was calculated based the envelope and skeleton density; specific surface area according to BET adsorption method; Pore size according to BJH method.

Type of coal		**Petroleum coke**	**Hardwood biochar 1**		**Hardwood biochar 2**
			unmilled	**milled**	
Skeleton density	[kg/m³]	2120.0	1494.0		1570.0
Spec. surface area	[m²/g]	2.2	142.1		166.6
Pore size	[nm]	12.1	6.0		5.9
Envelope density	[kg/m³]	848.0	459.0		459.0
Water content	[% wet weight]	0.3	5.4		6.3
Ash content	[% dry weight]	1.8	7.8		10.5
Volatiles	[% dry weight]	0.4	18.8		13.1
C	[% dry weight]	95.4	79.3		83.2
H	[% dry weight]	0.2	2.9		2.5
Void fraction	[-]	0.60	0.69		0.71
d_m (mass weighted average diameter)	[mm]	0.45	1.69	1.23	0.63

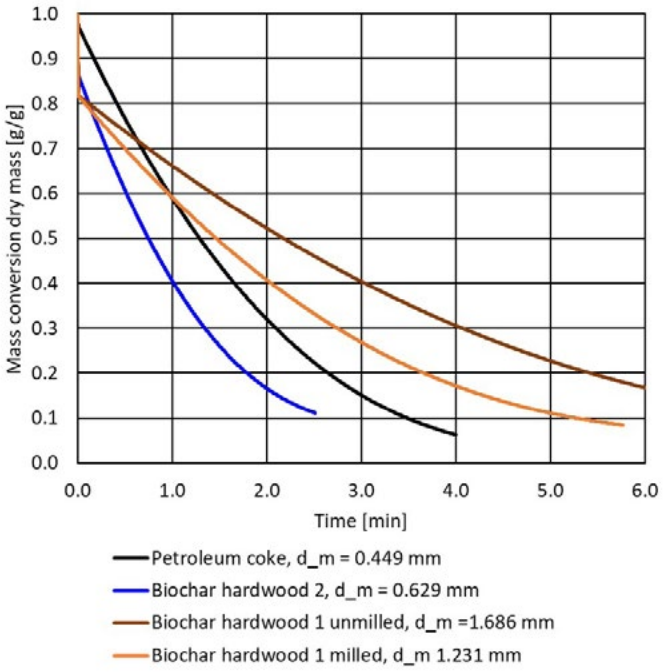

Fig.5 - Mass conversion over time (calculated on dry basis) for the conversion of biochar from hardwood and petrol coke during the time spent in the gas phase (before hitting the melt, left) and during the full fining phase (right) in the EAF
Explanations: d_m ...mass weighted mean particle diameter.

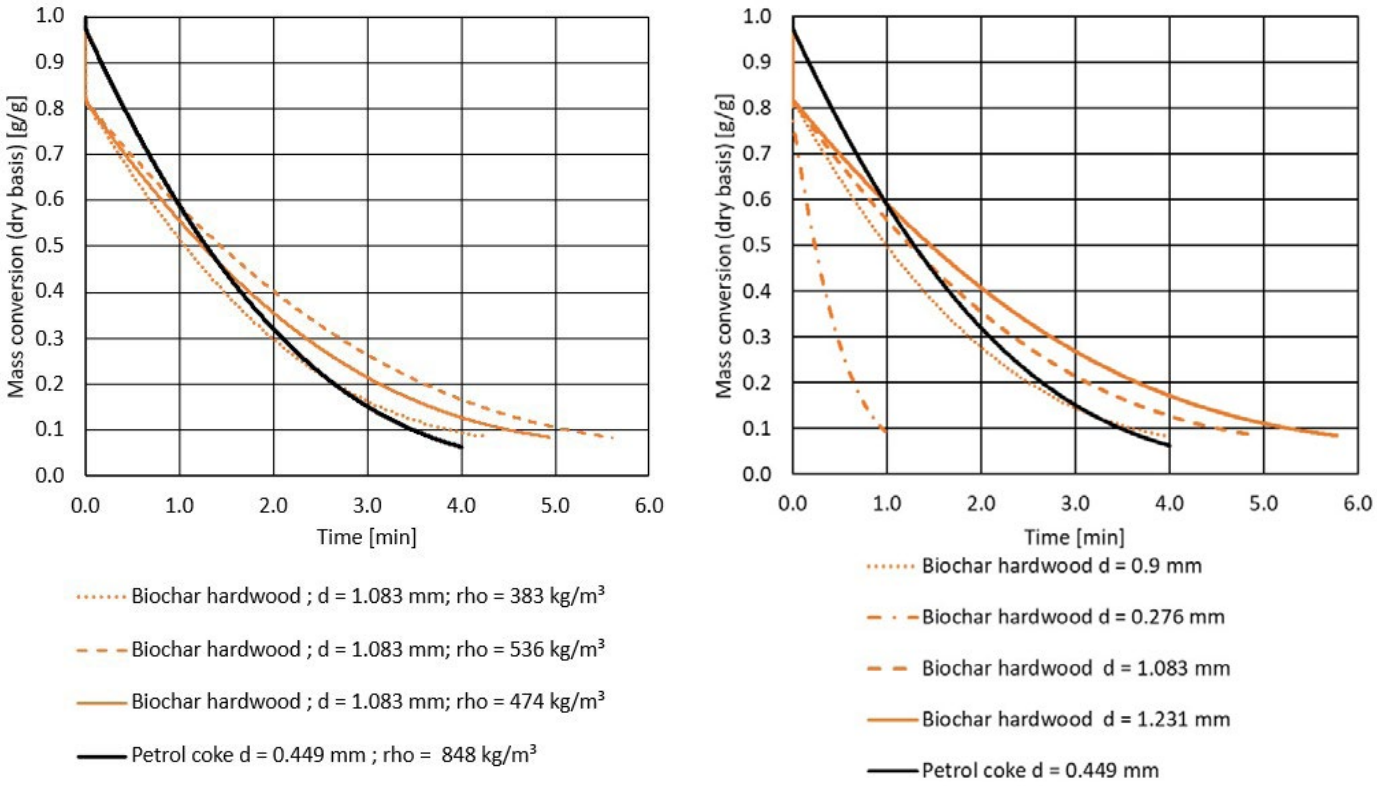

Fig.6 - Mass conversion over time (calculated on dry basis) for the conversion of biochar from hardwood and petrol coke under EAF conditions. Left: variation of biochar envelope density; Right: variation of biochar particle diameter.
Explanations: d ... average diameter, based on mass; rho ... envelope density i.e. density of a single particle including pores; envelope density of biochar in the right diagram: 474 kg/m³.

The primary influencing factors identified are as follows (see figure 6):

- Envelope density: A lower particle density (envelope density) results in a reduced decomposition time for a given diameter.
- Particle diameter: A smaller particle diameter also leads to a shorter decomposition time.
- Specific surface area and pore diameter: These parameters do not vary independently and can partially compensate for each other's effects on conversion behaviour.
- Volatile content: Volatile matter is released within seconds and does not contribute to slag foaming in the EAF. Consequently, a lower volatile content is advantageous, as it decreases the necessary amount of biochar for metallurgical applications.

The knowledge of the influence of different biochar properties on decomposition time makes it possible to define suitable biochar qualities which reach comparable decomposition times to fossil coke which typically should also result in similar slag foaming properties. The fact that the particle diameter has a significant influence on the decomposition time, enables, under consideration of the other relevant parameters such as envelope density, specific surface area and pore size, to tailor the foaming properties of the biochar by finetuning the particle size.

RESULTS INDUSTRIAL TRIALS

Parallel to the theoretical evaluation backed by lab-scale tests, full-scale trials at the EAF of Marienhütte were performed with biochar in several particle sizes, confirming the results of the particle conversion calculations. While tests with average particle sizes too small (d_m=0.63 mm) or too big (d_m=1.69 mm) didn't show relevant slag foam formation in the refining phase, biochar from hardwood with an average mass-weighted particle size of 1.23 mm showed acceptable foaming behaviour.

At Stahl- und Walzwerk Marienhütte GmbH a high productive AC-EAF with 40 t tapping capacity is in operation. The furnace is equipped with three side wall burners and one burner in the furnace door. Each of the side wall burners is able to inject carbon at a separate injection lance. The annual production capacity amounts to roughly 400.000 t. Marienhütte which is directly located in the city centre of Graz, the capitol of Styria in Austria, stands for an urban and sustainable production of rebars.

The trials performed with biochar from hardwood with particle size of 1.23 mm were done in 2025 at 7 heats in a row. Usually, petroleum coal is injected via all three side wall burners in the refining phase. Charging coal via basket is not used at Marienhütte in the production process. At these trials with biochar from hardwood one of these three injection points was equipped with a separate pneumatic injection vessel to be able to use either biochar and/or petroleum coke as slag foaming agent. Due to successful pre-trials with that material, it was decided to run for several heats solely with biochar as foaming agent and keep petroleum coke as back-up in case of problems or uncertainties. In total roughly 2000 kg of biochar were used in that trials. The results were rather promising and can be summarized as following:

- No visible differences in slag foaming in the refining phase
- Immediate start of the reaction and therefore slag foaming
- Solely no difference in yield values etc.
- No significant difference in FeO-content of slag
- No detectable changes in off-gas temperature, composition, etc.
- Slightly higher consumption of injection agent (approx. 20%) due to lower carbon content and higher volatiles content

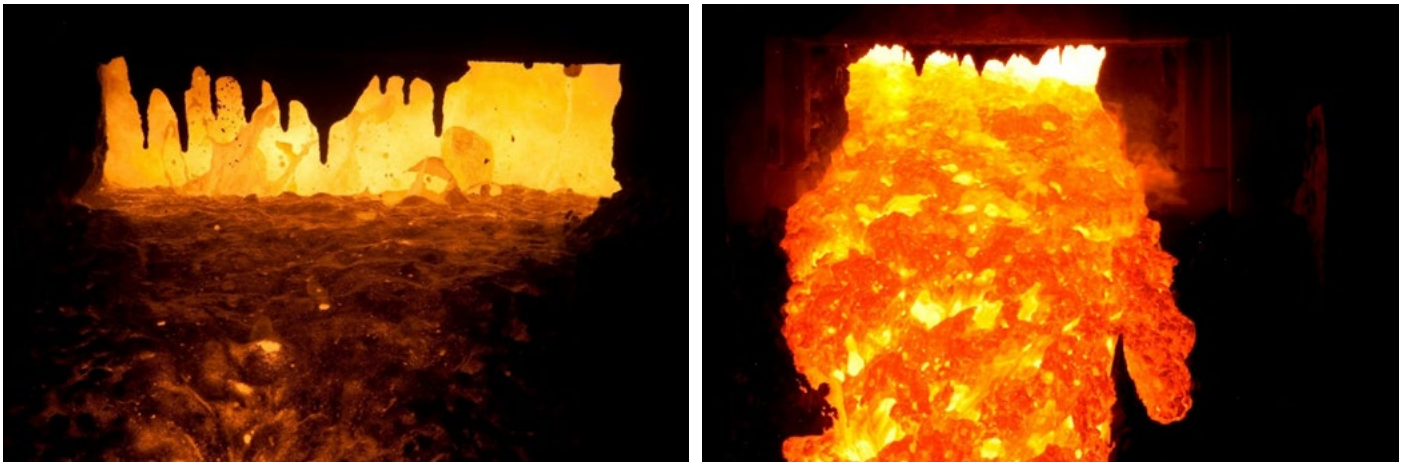

Fig.7 - Foaming slag operation at injection trials with biochar from hardwood.

Fig.8 - Graph of consumption values of oxygen (orange line), natural gas (blue line) and injection carbon (black line) as example for a heat during trial period.
Further trials with even better suited particle sizes (around 0.9 mm) are planned in 2026.

SUMMARY AND CONCLUSIONS

A novel adaptation of a layer model for single-particle conversion is presented, explicitly accounting for diffusion effects and dynamic changes in particle structure (e.g. specific surface area, porosity, pore diameter) during conversion. The model has been parameterized using both literature data and new experimental results and has been applied to both petrol coke as a reference and biochar under realistic EAF gas atmospheres (CO/CO_2 mixtures) and temperatures. This dual approach enables direct comparison and transferability of kinetic parameters across material classes. The research addresses a critical gap in the systematic evaluation of biochar for metallurgical use, by focusing on the conversion of coal particles under conditions typical for those applications.
The layer model accurately predicts the conversion be-

haviour of both biogenic and fossil coals. Key findings include:

- Particle density and diameter are primary influencing factors on conversion time; lower density and smaller diameter accelerate conversion.
- Specific surface area and pore size exhibit compensatory effects; increased surface area can be offset by reduced pore diameter due to diffusion limitations.
- High volatile content in biochar is disadvantageous for EAF use, as volatiles are rapidly released and do not contribute to slag foaming.
- The model supports the definition of optimal particle size and density for each type of biochar, ensuring comparable performance to fossil coal in EAF operation regarding slag foaming.

By establishing quantitative relationships among key material parameters (density, volatile content, specific surface area, pore size) and conversion kinetics, the study offers a rational basis for selecting and optimizing biochar for industrial applications. The findings provide actionable guidelines for the production and pre-treatment of biochar tailored to EAF injection, supporting decarbonization strategies in steelmaking. First successful trials with tailored biochar show that the findings can be transferred to industrial operations.

The validated modelling framework can be extended to other high-temperature applications, facilitating the broader adoption of renewable carbon sources in the metallurgical sector.

REFERENCES

[1] Ahmed, H., New trends in the application of carbon-bearing materials in blast furnace iron making. Minerals, 2018, 8, 561
[2] Feliciano-Bruzual, C., Charcoal injection in blast furnaces (Bio-PCI): CO2 reduction potential and economic prospects. Journal of Materials Research and Technology, 2014, 3, 233-243
[3] Suopajärvi, H. et al. Use of biomass in integrated steelmaking - Status quo, future needs and comparison to other low-CO2 steel production technologies. Applied Energy, 2013, 213, 384-407
[4] Fick, G. et al. Using biomass for pig iron production: a technical, environmental and economical assessment. Waste and Biomass Valorization, 2014, 5, 1, 43-55
[5] Bianco, L. et al. Sustainable EAF steel production (GREENEAF), Final Report. European Commission, Directorate-General for Research and Innovation, ISBN 978-92-79-33614-0 (2013)
[6] Cirili, F. et al. Biochar for a sustainable EAF steel production (GREENEAF2) – Final Report. European Commission, Directorate-General for Research and Innovation, ISBN 978-92-79-98291-0 (2018)
[7] R. Mehrabian, S. Zahirovic, R. Scharler, I. Obernberger, S. Kleditzsch, S. Wirtz, V. Scherer, H. Lu, L.L. Baxter, A CFD model for thermal conversion of thermally thick biomass particles, Fuel Process. Technol. (2012).
[8] E.T. Turkdogan, J. V. Vinters, Effect of carbon monoxide on the rate of oxidation of charcoal, graphite and coke in carbon dioxide, Carbon N. Y. 8 (1970) 39–53.
[9] R.H. Tien, E.T. Turkdogan, Incomplete pore diffusion effect on internal burning of carbon, Carbon N. Y. 8 (1970) 607–621.
[10] M.P. King, Carbon injection into electric arc furnace slags, Master Thesis, McMaster University, 2009.

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