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Optical emission spectrum measurement in on-line analysis of scrap melting in electric arc furnaces

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Abstract

The melting of scrap is important phenomenon in EAF process control, because it affects the heat transfer between the arcs and furnace sides. When the scrap on the furnace sides melts, higher amount of energy is transferred to refractories and cooling water. To keep the heat loss and the temperature of the side panels in acceptable levels, the melting of the scrap in the furnace sides is compensated either with reducing arc length or starting slag foaming.

Scrap melting has been traditionally monitored by measuring the temperature gradient of the side panel cooling water. However, there is a delay between the scrap melting and the increase of side panel cooling water gradient, which is proportional to the slag accumulated on the side panels. To alleviate this problem, the use of optical emission spectroscopy is proposed. In optical emission spectrometry the emission of light from EAF is analysed. The advantage of optical of optical emission spectrum measurement is that there is no delay between the scrap melting and the increase of the light intensity. The light emitted from the furnace can be gathered on with optical fibres installed to the furnace roof or burners and analysed with remotely placed spectrometers. The optical emission from different parts of the furnace can be measured simultaneously to gain information on the local scrap melting in EAF.

The results of the two measurement periods conducted in 2015 and 2016 in Outokumpu Stainless, Tornio works are presented. The results from the first measurement period illustrate the similarities and differences between side panel cooling water temperature gradient and optical emission measurement. The delay between optical emission spectrum measurement and side panel cooling water temperature gradient varied between no delay and a delay of minutes. In the second measurement period, optical emission spectrum measurement was used in on-line process control. The results of the second measurement period show the benefits and the feasibility of using optical emission spectrometry in on-line process control.

The microstructural scale of the interaction between Pig Iron (PI) and Hot Briquetted Iron (HBI) at high temperatures

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Abstract

A steelmaking facility, making products which contain little or no residual elements, is forced to use high-quality high-cost prompt scrap. An alternative route is to use a combination of the polluted obsolete scrap along with what is known as clean iron units, such as Pig Iron (PI) or Direct Reduced Iron (DRI).

DRI is an extremely flexible raw material to substitute high quality scrap in the electric arc furnace (EAF) route of steelmaking and its production amounts have increased drastically in last years. The addition in charge of DRI via Hot Briquetted Iron (HBI) is a promising challenge for the very next future in steelmaking, substituting scrap and even being used as the principal raw material to produce steel in EAFs. Indeed, in the usual practice, EAF-based producers use DRI from 20 up to 30 % of the typical charge weight, to improve the products quality by diluting impurities introduced by scrap. However, this change in the charged raw materials and consequently in the production cycle should not compromise products quality and economic margins, due to the strong competition featuring this industrial sector.

The EAF charge is commonly composed by 5% of pig iron; however, where scrap is scarce, PI may be used in quantities up to 60%. Since its high carbon content, the charge of PI results in a significant increase of the carbon content of the melt bath. Its consequent decarburization allows energy recovery from CO post-combustion, since it is an exothermic reaction. Also silicon and manganese, contained in the PI, act as a source of chemical heat. This could result as a very important source of chemical energy within the EAF and power savings could be achieved by using 10-15% PI in the charge. Moreover, due to the still oxidized volume of HBI, the carburizing environment generated by PI would grant beneficial effects on its yield.

In order to achieve the desired quality, a resulting fine microstructure has to be ensured. First, the characterization of both pig iron and DRI has been performed. Hence, to evaluate the microstructural evolution of pig iron and HBI interacting together at high temperatures, an experimental campaign has been conducted to clarify the occurring phenomena, simulating their behaviour within EAF. Moreover, the reactivity of DRI/HBI with the metal bath is well-known to be increased by a higher charging temperature. In this work, it has been demonstrated via the sessile drop method.

Charging of direct reduced iron in EAF: effect on yield

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Abstract

Worldwide, the greatest part of the ferrous scrap is recycled and refined to steel through Electric Arc Furnaces. EAFs are versatile, charging everything from all sorts of scrap to pre-reduced iron, pig iron and molten metal. The developments in the EAF technologies are focused on energy and environmental impact reduction, since the production process via the electric cycle currently provides very stringent limits on emissions. Resources optimization is essential for a proper energy management, due to the costs associated with raw materials and energy.

Each batch of steel that is produced is known as “heat”. The scrap yard operators classify and prepare buckets of scrap according to the chemical and production needs of the EAF. Nowadays, the melting operation provides different charge buckets, where different kind of scrap is charged inside. The addition of high quantity of shredded and local scrap can increase the concentration of undesired elements (eg. Sulphur, Copper) inside the metal bath. Different performance indices related to EAF steel production are used to evaluate the environmental impact. However, a more in depth analysis is necessary in order to evaluate the variation in yield due to the different scrap mixtures. In particular, the addition of HBI within the scrap buckets requires a specific analysis to optimize the charge yield, trying to use the same process parameters used during the normal charge.

Due to its high density and easy loading, HBI can lower the furnace dead times, helping to maximize the productivity avoiding the energy losses related to the furnace roof opening. Most charging operations use 2–3 buckets of scrap per heat. Usually, the different kinds of scraps are mixed in order to ensure proper melt-in chemistry and good melting conditions.

A specific experimental campaign has been performed in order to evaluate the difference in yield according to the different quantities and qualities of charged scrap. Also, the selection of the second scrap bucket for charging pre-reduced iron results fundamental, in order to recover the iron oxide that is still present within HBI. The tests shows how the adoption of HBI can be considered a good operational practice both for the increase of the melt yield and for the decrease of the high quality scrap inside the EAF cycle. This reduces the environmental impact, without negatively influencing the production and avoiding the increase in undesired elements concentration, related to the charge of low quality scrap.

The past and the future of RFCS funded EAF research - results of the VALEAF project

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Abstract

The objective of this work was to disseminate and valorise the results of the projects carried out in the frame of the European Research Fund for Coal and Steel (RFCS programme) and before European Community of Coal and Steel (ECSS) concerning the technology of Electric Arc Furnace (EAF).

From 1991 up to now, in the context of the research programmes of the European Coal and Steel Community (ECSC) and Research Fund for Coal and Steel (RFCS) about 70 projects have been dedicated to the EAF, 33 in the period 2001-2015. In the various projects all the most important players of European industry were involved (steel industry, engineering companies, suppliers, research centres). The research and demonstration projects have been carried out on different aspects of EAF technology, aiming at improving the process performance in terms of energy and resource optimisation, flexibility and environmental impact.

The critical analysis of the results obtained in more than 60 EU funded projects with respect to the main topics of EAF technology has been carried out. The most important results in these fields were selected for valorisation and dissemination within a series of seminars and workshops, which turned out to be a useful step forward to diffuse and favour the exploitation of the findings, and to provide a clear picture of the actual status of European EAF technology.

Finally future industrial targets and requirements for further research activities were identified, and a roadmap for future developments of EAF technology was defined.

Sensitivity study on electric arc furnace dedusting system model based on the input leak air calculation

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Abstract

Electric arc furnaces (EAF) are commonly employed in the industry to produce the molten steel by melting the steel scrap. The off gases formed during the steel making are removed via the dedusting system. The extracted flow from the dedusting system also contains the leak air through the slip gap embedded between the EAF furnace elbow and the hot gas duct. The amount of the input leak air only approximately can be determined due to the complicated flow condition. There are different methods to calculate the leak air volume flow rate: first method: applying Bernoulli's equation as main equation and by the corresponding cross-sectional area of the annular slip gap, second method: calculation according to the nitrogen amount of the extracted gas from dedusting system, third method: factor approach based on the oxygen availability and the post combustion efficiency and fourth method: specification of leak air amount with the draught force of fan which is installed to extract the off gas from the EAF. In this work all four methods are implemented in Matlab Software and they are connected to the IOB dedusting system model individually. In the next step a sensitivity study on off-gas temperature, volume flow rate and composition from EAF dedusting system is conducted based on the input leak air calculation. Furthermore the applied parameters in the leak air calculation like the sip gap size and the draught force of the fan prepare practical knowledge of the system. The capability of further application of these parameters in the control of electric arc furnace and dedusting system is also investigated in this work.

Spectrometric and Vibration Measurements at a 140 t DC Electric Arc Furnace for On-Line Evaluation of Scrap Meltdown Behaviour

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Abstract

Georgsmarienhütte GmbH, the Helmut-Schmidt-University Hamburg and further partners collaborate in an EU-funded project focusing on Electric Arc Furnace process control. Aim of the project is the integration of novel sensor data and advanced process modelling tools. Object of demonstration is Georgsmarienhütte's 140 t DC Electric Arc Furnace.

First steps in the project focused on test and installation of two novel vibration sensors, which hold independent directions of sensitivity at the above-mentioned furnace, aiming at reliable and significant measurement signals. For this purpose, a suitable measuring point is located. Analysis software modules for long term measurements as well as models for scrap meltdown behaviour, based on the novel sensor signals, are developed.

Moreover, an existing spectrometer system has been developed further. This system has previously been used for detecting free-burning arc conditions and was installed in a water-cooled wall panel, thus providing a direct view into the furnace. Novel research focuses on development of methods for on-line evaluating solid scrap amount and scrap height inside the furnace. As the spectrometers' view openings are prone to blockage by slag caking, the main challenge with spectrometric measurement equipment is to render continuous data. Therefore, purging mechanisms are improved and analysis algorithms are refined to automatically detect blocked or impaired view conditions.

Ultimately, a data interchange network is implemented in order to correlate the novel sensor data with other process data. The new sensor data are merged into an advanced on-line meltdown model. This combined model is also supported by a model of the electric arc foot and a scrap basket filling index. Applying the new model, scrap charging may be optimized and hot or cold spots may be detected. Thus the model provides a novel approach for homogenizing the meltdown behaviour.

Modelling of the Gas Phase in an Electric Arc Furnace Process Simulation Model

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Abstract

The electric steelmaking through the electric arc furnace (EAF) is the second most important steel production route in the world and the main process route for steel scrap recycling. As energy intensive process, the EAF is in the focus of energetic optimization to increase the energy and resource efficiency. Process models and simulations are able to contribute to a detailed understanding of energy and mass transfers during the melting process and can be applied to investigate new control strategies, waste heat recovery potentials or to assist the operator. Especially the EAF off-gas offers development opportunities, due to its energy output of approximately 20 – 30 % of the entire energy input and the possibility of process control through off-gas measurements.

Within the presentation, the comprehensive modelling of the gas phase in an EAF process simulation model and the validation process is described. The process simulation model is based on the EAF model described by Logar, Dovzan and Škrjanc in 2012, which was developed in accordance with fundamental thermodynamic and physical equations. While the majority of existing EAF models is mostly described as black box models, the presented model is well publicized and can therefore be used as a basis for future model developments. For modelling the gas phase, the basic process model from Logar et al. was re-implemented and the gas phase and the corresponding phenomena further developed. Hydrogen, water and methane were added to the gas phase as well as new reaction mechanisms. Next to dominant equilibrium reactions like water-gas reaction and Boudouard reaction, further simple reaction mechanisms like water dissociation and post combustion reactions are included. As a new zone, the electrode and its cooling are considered and the thermal radiation is improved, as the gas radiation is now implemented. The simulation results are compared to data from an industrial scale EAF regarding the off-gas mass flows and the enthalpy of the off-gas. In contrast to statistical EAF models, the deterministic implementation allows a fast and easy adaptability to various EAFs and a detailed investigation of energy and heat distribution and mass transfers inside the EAF. By help of detailed gas phase simulations, further research on control strategies is possible.

Foaming Slag Management by Process-Controlled Feeding of Fine Coal at a 165 t AC Electric Arc Furnace

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Abstract

ArcelorMittal Hamburg GmbH (AMH), Helmut-Schmidt-University and other partners collaborate in a joint research project funded by the Federal Ministry for Economic Affairs and Energy (BMWi) aiming to increase the efficiency of energy input into electric-arc-furnaces (EAF) by process-controlled and process-regulated feeding of energy carriers. Object of demonstrations is the 165 t AC EAF of AMH.

In order to produce crude steel for new steel products, scrap and directly reduced iron (DRI) are melted in an EAF using electric and chemical energy. In this process, continuously foaming slag is indispensable for two main reasons. Firstly, slag thermally insulates the furnace vessel and thereby prevents heat-related damage. Secondly, slag assists the transfer of the electric arcs' thermal radiation into the melt, thus reducing thermal losses.

The slag's foaming behaviour is especially affected by fine coal and DRI. A process-controlled regulation of DRI feeding is already installed at AMH, so in this current project, the focus will be on the analysis and regulation of fine coal injection. Fine coal plays an important role in the foaming process as it chemically reacts with oxygen, forming carbon monoxide bubbles and thereby expanding the slag layer in the desired manner.

The feeding of fine coal into the furnace is realised by three jet-boxes, which may be regulated independently. At the moment, feeding is regulated manually. The aim of this project is to develop a process-controlled feeding of fine coal aiming at an optimised foaming behaviour and increased energy efficiency.

First steps in the project focused on the collection and evaluation of process-related data concerning fine coal injection, further fine coal-affecting parameters and parameters which allow conclusions about the actual foaming behaviour to be drawn. The latter include acoustic sound measurements as well as the furnace's active electric power. After classification, these data have been merged into first quantifiable and automatable strategies for fine coal injection in the form of mathematical models. Further, more elaborate models will be developed to integrate other process steps. These include, for example, the renewal of slag during the melting process.

LCA Case study: Environmental impacts of the biochar usage in the Electric Arc Furnace

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Abstract

The environmental impacts of the usage of biochar during electric steelmaking in the EAF were investigated by a Life Cycle Assessment (LCA) case study including process data of three different steel plants. A LCA is a tool to quantify and evaluate the environmental burdens and impacts of product systems. This tool is mainly used by industries, governments and environmental groups to assist with implementing environment-related strategies and material selection. Therefore a LCA study is a suitable tool to evaluate the biochar usage during EAF steelmaking.

The LCA studies about the utilization of biochar in the EAF were carried out to compare the usage of fossil and biogenic carbon carriers. Therefore the modelling is focused on the melting process in the EAF without any upstream and downstream processes to calculate the CO2 intensity of the electric steel production.

Process data of three steel plants, Ferriere Nord (IT) Marienhütte (AT) Georgsmarienhütte (D) were collected, clustered and implemented into the LCA model. In a first step reference heats using fossil carbon were analysed. After that, the biochar usage was investigated by a progressive substitution of fossil coal. Mass balances and CO2 equivalents were calculated to realize an objective comparison between the usage of fossil and biogenic carbon during the steel melting process.

These melting experiments in industrial scale were carried out and evaluated by analysing the produced steel, slag composition, (off gas composition) and the demand of electric energy. From a technical point of view the usage of biochar during electric steelmaking is possible and has neither any negative effect on the process nor on the final product steel.

Indication of flat bath using acoustic measurements in a 6 ton AC EAF

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Abstract

The increased awareness of environmental consequences of the fossil fuel consumption has further increased the demands on the industry to adapt to more energy efficient processes with lower emissions. In addition to these demands, increased recycling rate of steel scrap will in the future require an increased use of the electric arc furnace (EAF) process. Hence the operation of the EAF must be improved in the future. One of the bigger questions regarding an improved electric arc furnace operation is the consumption of electric energy, which is the main source of heat in the furnace. To reduce the energy consumption in the furnace, it is necessary to decrease the energy losses.

The thermal losses of the arcs are higher when the scrap level in the furnace is low. In addition, the stress on the furnace walls and cooling system is higher. Consequently, it would be beneficial to be able to decide the arc power based on the amount of scrap in the furnace. The latter proves a difficult object to overcome due to the fact that the furnace is closed during operation. The common practice today to estimate the amount of un-melted scrap in the furnace is to use metallurgical energy calculations and statistical modelling. However, the scatter in the result is still very large. Nonetheless, the implementation of more useful measurement techniques may provide more variables to increase the stability of modelling and to help understand the meltdown procedures. One way is to use the sound and vibrations emitted from the arcs and try to find their relationship to parameters controlling the meltdown process.

This work investigates what frequencies that have the best correlation to the presence of a flat bath when using both microphone and accelerometers measurements. Furthermore, this work utilizes a small furnace which allows for a better control of the process along with the acoustic environment.

In total 15 charges were observed during the course of their meltdown. The total signal amplitude along with the amplitude of individual frequencies were observed especially when approaching the end of meltdown. It was found that a clear change in furnace acoustic output could be observed looking both at certain harmonics of 50 Hz and the amount of frequency bands spanned. This was observed independently of furnace power and it is a strong indication of flat bath formation and will be analysed in-depth in future investigations.

Investigation of the suitability of biogenic materials for the application in EAF steelmaking as substitutes for fossil resources

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Abstract

Investigations were carried out on the suitability of biomass for the substitution of fossil coal in EAF steelmaking. Assessing the suitability of various biomasses for the use in the electric steel route was conducted by different laboratory tests.

Seven biogenic materials were chosen to be investigated. The first phase of the investigation included a material and X-ray fluorescence analysis of the samples to estimate the impact of specific material parameters on the crude quality and the manufacturing.

In a second step, the reactivity and the reaction potential of the biomasses were examined. A reactor was designed in accordance with DIN 51720, the standard for "Testing of solid fuels – Determination of volatile matter content" at the Department for Industrial Furnaces and Heat Engineering (IOB) for these analyses. In order to determine the reactivity and the reaction potential of the chosen materials, the samples were investigated in the reactor that was tempered to 900 °C using a gas analysis system. Nitrogen and air were used as purge gases to investigate the degassing and combustion behaviour. Based on the logged concentration profiles of the exhaust gases and the known purge gas flow the specific production masses and specific production rates of degassing components were determined. In general the results show that the experimental setup provides a qualitative and quantitative assessment of the reactivity and the reaction potential of biomasses. The results of the reactivity tests show that the reactivity and the reaction potential are not in a direct context to the results of the material and X-ray fluorescence analyses. Physical properties such as the specific surface, the density or the structural formula of the samples also influence the reaction kinetics.

The next step was to study the foaming potential of the samples in liquid slag. Slag from an industrial EAF was molten in a Tammann furnace. The samples were charged into the liquid slag at 1600 °C. The solidifications at the crucible side indicate the rise of the foamed slag. It appears that the amount of volatile matter contained in the samples scales with the material's foaming capacity.

Overall the results of the various investigations showed that biomasses are suitable for the application in electric arc furnaces. As a continuation of this study, the investigations of other biomasses as well as blends of different biomasses and pilot-scale trials to improve the scale-up are recommended.