CHEMICAL ENGINEERING TRANSACTIONS

VOL. 52, 2016

A publication of AIDIC

The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Peng-Yen Liew, Jun-Yow Yong, Jiří Jaromír Klemeš, Hon Loong Lam

ISBN 978-88-95608-42-6; **ISSN** 2283-9216

DOI: 10.3303/CET1652128

Improving Sustainability of Electric Steelworks through Process Simulations

Ismael Matino*[a], Valentina Colla[a], Vitantonio Colucci[a], Pietro Lamia[a], Stefano Baragiola[b], Cosmo Di Cecca[c]

[a]Scuola Superiore Sant'Anna, TeCIP Institute – ICT-COISP, Via Alamanni 13B,56010 Ghezzano, Pisa (Italy)
[b]RIVA ACCIAIO S.p.A., Via Bergamo 1484, 21042 Caronno Pertusella – VA (Italy)
[c]Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano (Italy)
i.matino@sssup.it

The European Steel sector is committed to investigate solutions for reducing its environmental impact in terms of atmospheric and water emissions, energy consumption and solid waste production. To this aim, the project entitled "Environmental Impact Evaluation and Effective Management of Resources in the EAF Steelmaking" (EIRES), that is funded by the Research Fund for Coal and Steel, aims at providing electric steelworks with a tool for a systematic evaluation and investigation of solutions improving the process sustainability. As complex process modifications, before being practically implemented and tested on the field, need a thorough evaluation, a simulation model of the whole electric steelmaking route was developed as a part of EIRES tool. The paper presents such simulation model, which has been developed through Aspen Plus® V 8.6 in order to assess the impact of each operation unit, including both production processes and fumes and wastewater treatment plants. A case study is presented, which compares the environmental and energy impact related to the production of some of the most commonly produced steel grades. Correlations between the steel grade and the consumed electric energy or the slag amount and composition were highlighted, that can be a useful starting point for further assessment of potential margins of improvement of electric steelwork sustainability.

1. Introduction

Nowadays the European steel industries face a number of challenges concerning production costs, environmental impact and sustainability. These aspects are usually connected among each other: production costs could be reduced through a more efficient resource and energy management, an enhanced recycling of wastes and by-products and a reduction of emissions (e.g. carbon dioxide, wastewater). These factors are also affecting the environmental impact and sustainability of the production process. Furthermore, ever more stringent environmental regulations and increasing of energy and raw material costs led steelmaking industries (both integral and electric routes) to focus most of their efforts toward these issues, as well as toward tools for efficient monitoring of each aspect related to the plant sustainability. For these reasons, several studies and projects have been developed in this context and many of them exploits Process Integration, Simulation and Optimization as main instruments. The REFFIPLANT project is an example of a recent RFCS project focused on the improvement of efficiency of resources (materials, water, energy) in integrated steelmaking plants by minimising them at source or finding integrated solutions for their reuse. Several scenarios were analysed and intensive simulation studies were carried out. From the point of view of water reuse, Alcamisi et al. (2015) presented the adopted simulation approach and Matino et al. (2015a) modelled a pipe mill washing water network of an Italian steelworks in order to evaluate the partial replace of fresh water with the pipe coating blowdown water. Considering the reuse of by-products, Colla et al (2015) carried out a comparison of oily millscale treatments in order to make this by-product suitable for internal reuse, while Matino et al (2015b) assessed a BOF slag treatment through simulation and experimental trials in order to verify the possibility of the reuse of the two main fractions of the slag. Such studies and the overview

Please cite this article as: Matino I., Colla V., Colucci V., Lamia P., Baragiola S., Di Cecca C., 2016, Improving sustainability of electric steelworks through process simulations, Chemical Engineering Transactions, 52, 763-768 DOI:10.3303/CET1652128

of the exploited simulation techniques given by Matino et al. (2015c) highlight an approach that can be exploited also in the case of electric steelworks for similar purposes. The importance of Process Integration in achieving efficiency improvement was also highlighted by Porzio et al. (2013a) in a study devoted to the reduction of energy consumption and CO_2 emissions in an integrated steelmaking. The same kind of analysis was widened and deepened in Porzio et al. (2013b). In the same way, Ghanbari et al. (2013) proved that the energy efficiency of an integrated steelwork can be increased by integrating steelmaking with a polygeneration system. Also in the field of electric steelmaking, several works and projects (e.g. PROTECT, OPCONSTAINLESS or FLEXCHARGE) are related to the improvement of plant sustainability and to the minimizing of production costs. Electric steelworks are currently producing almost one third of the total steel, as said by Yan (2015), and this percentage is supposed to rise in the future. The study of Lingebrant et al. (2012) is an example of a Simulation and Optimization study with the aim of reducing production costs optimizing scrap and energy mix and monitoring main process parameters. In addition, Porzio et al. (2016) simulated the possibility to simultaneously preheat the scrap and remove the coating from their surface before the melting phase in order to find a way to avoid harmful dusts and air emissions and to recover valuable material (e.g zinc). Starting from these topics and in a more general view, the RFCS project “Environmental Impact Evaluation and Effective Management of Resources in the EAF Steelmaking” (EIRES) started in 2013 and it has the ambition to give a general-purpose tool in order to evaluate the environmental impact of current operating practices, modified operating conditions and major process modifications and innovations. In this way, process can be monitored in current operating conditions and plant modifications can be assessed in order to improve electric steelmaking plant sustainability. The work presented in this paper is focused on one of the simulation tool developed through Aspen Plus® V. 8.6 and part of EIRES tool. A case study using the developed model is shown in order to compare the impact of the production of different steel grades using the Key Performance Indicators (KPIs) also defined in EIRES project. The definition of suitable KPIs is of utmost importance in order to monitor, assess and predict the impact of industrial processes, such as discussed in the work of Tahir and Darton (2010), where a method is described to select such indicators, which was also considered within EIRES.
The paper is organized as follows: Section 2 presents a background on the materials and methods used in the modelling phase, Section 3 describes the model (i.e. production processes, water and off-gas networks sub-models) and an example of its use is presented in Section 4, while Section 5 proposes concluding remarks.

2. Materials and methods

A complex model has been developed to represent the overall production chain and treatment units of an Italian electric steelworks. The development of the model was carried out following a well-structured methodology according to which literature, process and data analyses are fundamental steps allowing the implementation of a representative “virtual plant”. For this reason, a strict collaboration with the company staff was essential in data and know-how acquisition: production manuals, flowsheet, Piping and Instrumentation Diagrams (P&IDs), stream flowrates, data registered during the industrial practices were shared and deeply examined. Commercial software Aspen Plus® V. 8.6 was used in the modelling and simulation stage. Chemical species of the software internal databanks were selected and used together with an ad-hoc modelled complex specie (i.e. lubricant oil) modelled starting from datasheets, distillation curve and API gravity. Unit operations and process phases were modelled through both internal libraries and “unit blocks” and ad-hoc written calculator modules that were combined together in order to consider all the relevant process aspects. The developed models were connected through MS Excel® exploiting Aspen Simulation Workbook®, that allows controlling the main sub-models (i.e. production process, water and fumes networks) both as stand-alone tools or linked to each other. Such connection also allows the joint use of the model and of the other sub-tools of the EIRES system, such as a KPIs calculation tool. The model was developed exploiting real data, by means of a tuning procedure that aims at matching at best real and simulated data related to selected monitoring points of the process. Eleven steel “families” have been identified, each grouping steel grades with similar features. The tuning procedure was repeated for each steel family and the model was considered validated if energy and mass balances were respected and if the error between real monitored data (e.g. steel composition, energy contributions, temperatures) and simulation results was below threshold agreed with the technical personnel of the steelwork. For some parameters, the obtained error was lower than 2 % and in other cases the accuracy is lower but still acceptable for the model purposes.

3. Description of the developed electric steelwork model

The electric steelwork was modelled according to RIVA S.p.A. plant located in Caronno Pertusella (Italy) and three sub-models related to the production chain, the water network and the fumes network form the complete model. In this way, each aspect of the whole production route is taken into account and each parameter affecting the sustainability of the plant is monitored. Although the model was developed considering a particular steelworks, it is customizable and modifiable in order to be adapted to other plants.

The production chain model is the more complex one and a detailed description of its modelling is given in Matino et al. (2016). The model considers each process aspect, starting from the charging of Electric Arc Furnace (EAF) with metallic (e.g. scrap) and non-metallic materials (e.g. anthracite, lime) and reaching the beginning of the continuous casting. Each step related to EAF melting, refining and de-slagging (Figure 1), Ladle Furnace (LF) refining and de-slagging, Vacuum Degassing (VD) and energy losses related to Continuous Casting (CC) are modelled. The user have to feed the model with scrap and non-scrap charge, Fe-alloys and other added compounds, temperatures in some process points, vacuum pressure and burners charge. Three main scrap types are considered (i.e. sheet metals, proler and other types) and their initial composition was tuned starting from literature data and using a sort of simplified regression model in order to fit RIVA data about melted scrap mix. The model computes phase transitions (e.g. scrap or Fe-Alloys melting) exploiting internal libraries or ad-hoc FORTRAN-based calculator blocks in order to calculate involved energy and mass transfers. The main reactions (e.g. oxidation of Fe-Alloys, decarburization reaction) as well as energy (e.g. during the ladle transportation) and material losses are taken into account. A specific "hydrogen line" is implemented in order to manage the hydrogen content during the whole route according to hydrogen formation (e.g. due to the moisture) and solubility in the melted steel, which is affected by temperature and pressure. The model allows the computation of mass, temperature, composition of steel, slags and fumes and the evaluation of energy requirement (chemical, electric and from burners) and losses. A portion of the production model is shown in Figure 1, which refers to the EAF de-slagging and refining stage. Although it is only a portion, the complexity of the model is evident: there are several reactors, separators, exchangers and calculators and many streams are contemplated (e.g. steel, Fe-alloys, slag and fumes) by considering all the most relevant process aspects. Real or simulated (from the production model) data related to the produced fumes are the input for the fumes network sub-model: flowrates, composition, temperatures, pressures. The fumes come from the EAF, the doghouse, the LF and from the VD. In the model the main separation and energy recovery stages are considered such as dust catchers, bag filters, exchangers. Moreover, the post-combustion of CO to CO_2 was considered in the model representation of the 4th hole. In this sub-model, such as in the production chain model, the VD unit operation and each related line (e.g. mass lines for steel and fumes) can be excluded if VD is not required in the production of a steel grade. The fumes network model allows computing each features of the different fumes during the whole treatment process: their amount and composition (e.g. CO_2 and main air contaminant content), the dusts amount collected during the treatment and released in air and their composition, temperatures, pressures and recovered thermal energy. The last sub-model is related to the water network and is depicted in Figure 2. The model computes the freshwater consumption starting from the amount of steel to be casted, the temperatures to be reached in the different water using processes (simplified as exchangers) and considers the main water losses due to evaporation, to the entrained water and to the water blowdown. The water contamination is modelled exploiting the following unit operations: accumulation and recirculation tanks, decanters, filters, scale and oil separators and thickeners. CC is the main contamination process and it is represented in a simplified way as a contaminant producer (oil, scale and powder lubricant). The model allows calculating heat exchange, thermal energy recover, amount and main features (e.g. pH, conductivity) of the water streams and of the produced by-products/waste (e.g. scale or sludge).

4. Relationship between environmental and energy parameters and produced steel grade

The whole developed model was used to verify if the steel grade affects the environmental parameters and the energy consumption. In this way, indications for improving the environmental impact of the production chain can be obtained in order to improve the sustainability of the production process.

To this aim, 4 frequently produced steel grades were selected and their production was simulated: 3 steel grades belonging to the family named 5 (wt%: C = 0.12-0.25 %, Si ≤ 0.5 %, Mn = 0.9-1.6 %, Cr ≤ 0.25 % , Ni ≤ 0.25 %, B≤0.0008 %) and 1 belonging to the family named 8 (wt%: C = 0.25-0.7 %, Si ≤ 0.5 %, Mn ≤ 1.6 %, Cr = 0.1-0.8 %, Ni ≤ 0.9 %, B ≤ 0.0008 %). The assessment was carried out using the simulation results to compute some of the EIRES defined KPIs presented by Colla et al. (2016) and in particular:

- KPI 2 - Direct specific electrical energy consumption;
- KPI 5 - Direct specific CO_2 emission;
- KPI 15 - Specific EAF slag production;
- KPI 18 - Specific LF slag production;
- KPI 21 - Total output of slag;
- KPI 22 - Specific dust production and separated in the flue gas filters;
- KPI 29 - Specific freshwater consumption.

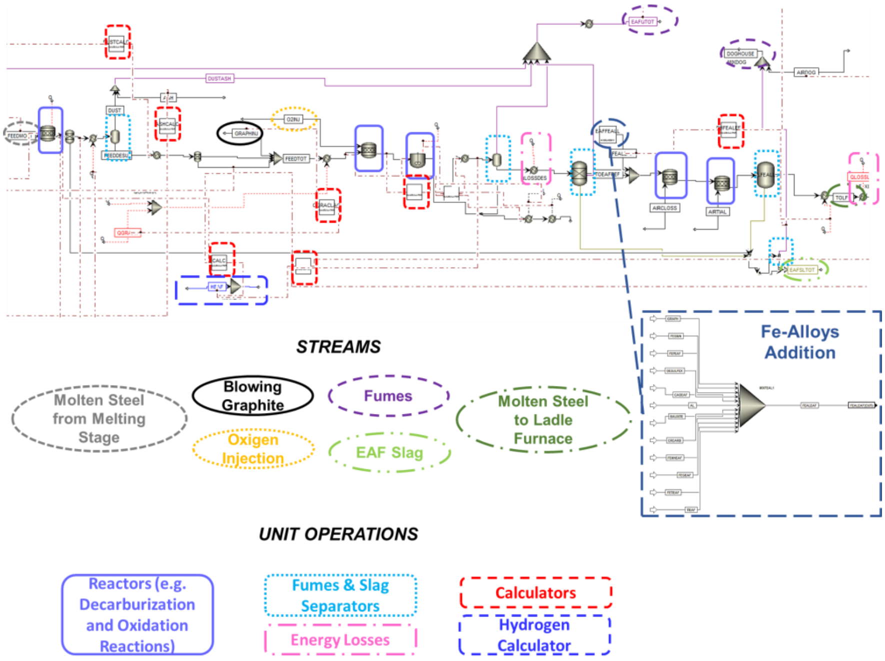

Figure 1: Aspen Plus® model flowsheet of the portion related to EAF de-slagging and refining stages.

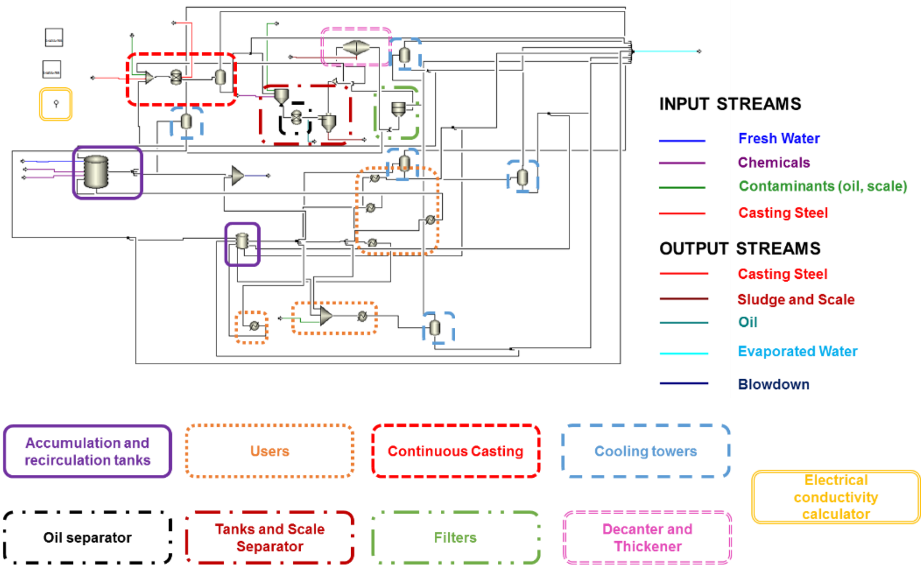

Figure 2: Aspen Plus® model flowsheet of water network.

The obtained results are shown in Figure 3, where the KPIs values are normalized with respect to the associated mean values related to 3 years of production (2012-2014) for confidentiality constraints. The steel grades belonging to the same family (5A, 5B, 5C) have similar behaviour in terms of required electrical energy and only negligible differences arise in by-product and waste productions. On the other hand, steel grades belonging to different families (5 and 8) show significant differences especially in LF slag amount (KPI 18) and in the required electrical energy (KPI 2). The distribution of electric, burners and chemical (due to reactions) energy in EAF was evaluated and the values are reported in Table 1. The percentage distribution of the three kinds of energy is almost the same in the four considered steel grades. Water consumption (KPI 29) and dust production (KPI 22) appear not to be affected by the type of produced steel. The model calculated the EAF and LF slag composition as reported in Figure 4 for the steel grade 5A and 8A and as expected different slag compositions (especially from LF) were obtained by steels belonging to different families.

Table 1: EAF energy contribution

Steel Grade	Electric Energy [%]	Chemical Energy [%]	Burners Energy [%]
8A	75.2	20.8	4.0
5A	74.9	21.2	3.9
5B	75.0	21.0	4.0
5C	75.1	20.8	4.1

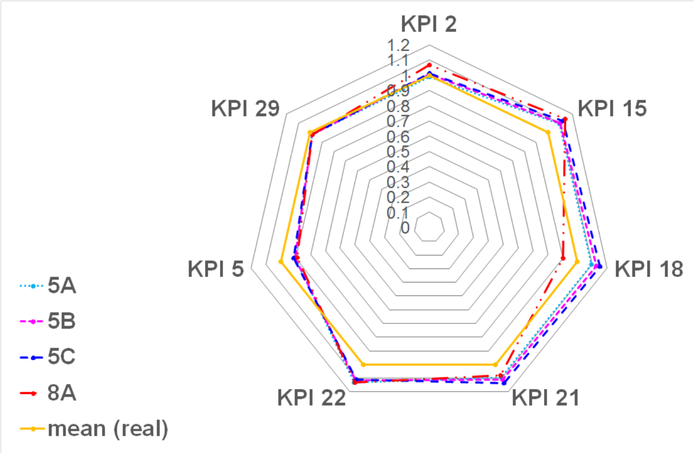

Figure 3: Comparison between KPIs related to the production of different steel grades

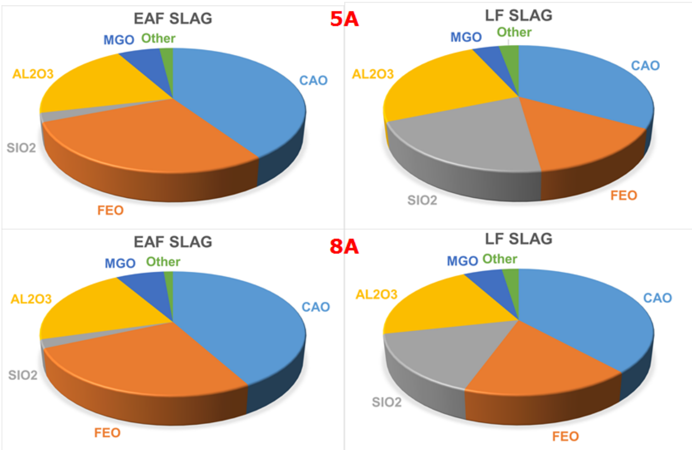

Figure 4: Comparison between slag compositions (wt%) related to the production of two steel grades

5. Conclusions

A model of an electric steelmaking route is presented and the main sub-models related to the production chain and the water and fumes networks are described. Such model was used to assess the dependency of environmental and energy parameters on the produced steel grade. The evaluation was carried out using the model results to compute some previously defined KPIs. Clearly steel grades belonging to the same families have similar impact. On the other hand, differences exists between steel grades of different families in particular in terms of by-products production and features and of electric energy consumption. These results give useful indications about the current process operations and provide hints for evaluating possible process modifications in order to improve energy and resource efficiency and production sustainability. For instance, the knowledge of slag composition, that is not currently monitored, can be used to maximize the slags internal reuse if their composition (e.g. FeO, CaO content) is suitable to partially replace some raw materials (e.g. scrap or lime). This solution could increase plant sustainability especially in the case of steels for which the production of slag is greater. Future investigations will be devoted to simulate un-common scenarios to the aim of maximizing the reuse of by-products or to elaborate new process operating conditions that allow reducing the environmental impact of the production process. The paper puts into evidence that a well-designed and properly tuned model can be a very powerful tool for scenario analyses aimed at finding margins of improvements for the sustainability of electric steelworks.

Acknowledgments

The work described in the present paper was developed within the project entitled “EIRES” (Contract No. RFSR-CT-2013-00030), and received funding from the Research Fund for Coal and Steel of the European Union, which is gratefully acknowledged. The sole responsibility of the issues treated in the present paper lies with the authors; the Union is not responsible for any use that may be made of the information contained therein.

References

Alcamisi E., Matino I., Colla V., Maddaloni A., Romaniello L., Rosito F., 2015, Process Integration Solutions for Water Networks in Integrated Steel Making Plants, Chemical Engineering Transaction, 45, 35-42.

Colla V., Matino I., Alcamisi E., Porzio G.F., Romaniello L., Rosito F., 2015, By-Products Recycling in Iron & Steel Plant: Comparison between Oily Millscale Treatments, Proceedings of 2nd European Steel Technology and Application Days – ESTAD 2015, Dusseldorf, Germany.

Colla V., Cirilli F., Kleimt B., Inamuno I., Tosato S., Baragiola S., Klung J.S., Quintero B. P., De Miranda U., 2016, Monitoring the Environmental and Energy Impacts of Electric Arc Furnace Steelmaking, Matériaux & Techniques, 104, 102.

Ghanbari H., Saxén H., 2013, A Techno-Economic Analysis of Using Residual Top Gases in an Integrated Steel Plant, Chemical Engineering Transactions, 35, 169-174.

Lingebrant P., Dahl J., Larsson M., Sandberg E., 2012, System Optimization of an Electric Steel Making Plant with Sequenced Production and Dynamic Stock Level, Chemical Engineering Transactions, 29, 523-528.

Matino I., Colla V., Alcamisi E., Porzio G.F., Romaniello L., Rosito F., 2015a, Evaluation of Water Blowdown Reuse in Integrated Steelworks through Process Simulation, Proceedings of 2nd European Steel Technology and Application Days – ESTAD 2015, Dusseldorf, Germany.Matino I., Branca T. A., Alcamisi E., Colla V., Romaniello L., 2015b Evaluation of a BOF Slag Recovery Treatment combining Experimental and Simulation Studies, Proceedings of 3rd International Conference on Sustainable Solid Waste Management – TINOS 2015, Tinos Island, Greece.

Matino I., Colla V., Romaniello L., Rosito F., Portulano L., 2015c, Simulation techniques for an efficient use of resources: an overview for the steelmaking field, Proceedings of World Congress on Sustainable Technologies – WCST-2015, London, UK.

Matino I., Alcamisi E., Colla V., Baragiola S., Moni P., 2016, Process modelling and simulation of electric arc furnace steelmaking to allow prognostic evaluations of process environmental and energy impacts, Matériaux & Techniques, 104, 104.

Porzio G.F., Colla V., Matarese N., Nastasi G., Branca T.A., Amato A., Fornai B., Vannucci M., Bergamasco M., 2013a, Process integration in energy and carbon intensive industries through exploitation of optimization techniques and decision support, Chemical Engineering Transactions, 35, 193-198.

Porzio G.F., Fornai B., Amato A., Matarese N., Vannucci M., Chiappelli L., Colla V., 2013b, Reducing the energy consumption and CO_2 emissions of energy intensive industries through decision support systems - An example of application to the steel industry, Applied Energy, 112, 818-833.

Porzio G.F., Colla V., Fornai B., Vannucci M., Larsson M., Stripple H., 2016, Process integration analysis and some economic-environmental implications for an innovative environmentally friendly recovery and pre-treatment of steel scrap, Applied Energy, 161, 656-672.

RFSR-CT-2007-00007, OPCONSTAINLESS – Resource-saving operation of stainless steel refining in VOD and AOD process, <bookshop.europa.eu/uri?target=EUB:NOTICE:KINA25087:EN> accessed 01.04.2016.

RFSR-CT-2007-00008, FLEXCHARGE – Cost and energy effective management of EAF with flexible charge material mix, <bookshop.europa.eu/uri?target=EUB:NOTICE:KINA25094:EN> accessed 01.04.2016

RFSR-CT-2010-00004, PROTECT - Processes and technologies for environmentally friendly recovery and treatment of scrap, <bookshop.europa.eu/en/processes-and-technologies-for-environmentally-friendly-recovery-and-treatment-of-scrap-protect--pbKINA27201/> accessed 01.04.2016

RFCS project RFSR-CT-2012-00039, REFFIPLANT- Efficient Use of Resources in Steel Plants through Process Integration, 2012-2015, <www.reffiplant.com/> accessed 01.04.2016.

Tahir A.C., Darton R.C., 2010, Sustainability indicators: using the Process Analysis Method to select indicators for assessing production operations, Chemical Engineering Transactions, 21, 7-12.

Yan J., 2015, Handbook of Clean Energy Systems, Volume 5, Wiley, DOI: 10.1002/9781118991978.