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Reducing the energy consumption and CO_2 emissions of energy intensive industries through decision support systems – An example of application to the steel industry

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HIGHLIGHTS

- We describe an application of decision-support system to iron and steel industries.
- The realised tool is useful in monitoring energy and CO_2 performances of the plant.
- Key processes are modelled through flowsheeting approach and included in the tool.
- A mathematical optimisation model for the process gas management has been realised.
- Implementation of the tool can help reducing plant costs and environmental impact.

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ABSTRACT

The management of process industries is becoming in the recent years more and more challenging, given the stringent environmental policies as well as raising energy costs and the always-present drive for profit. A way to help plant decision makers in their daily choices is to refer to decision-support tools, which can give advice on the best practices on how to operate a plant in order to reduce the energy consumption and the CO_2 emissions keeping at the same time the costs under control. Such an approach can be useful in a variety of industries, particularly the most energy-intensive ones such as iron and steel industries. In this paper, an approach to the realisation of a software system, which allows to generate internal reports on the plant performances, as well as to simulate the plant behaviour in different scenarios, is described. The main production processes (coke plant, blast furnace, steel shop, hot rolling mill) are described and simulated focusing on the prediction of products flow rates and composition, energy consumption and GHGs (Greenhouse Gases) emissions in different operating conditions. The importance of a correct management of the CO_2 within the plant is underlined, particularly with regard to the new EU Emission Trading System, which will be based on European benchmarks. The software tool is illustrated and a case study is included, which focuses on the simultaneous minimisation of the CO_2 emissions and maximisation of the profit through an optimised management of the by-product gases. The results from the case study show a good potential for process improvement, by a reduction in the cost and environmental impact.

1. Introduction

Steel industry is among the main energy-intensive manufacturing systems worldwide: according to the International Energy Agency (IEA), the iron and steel sector is the second-largest industrial user of energy, consuming 616 Mtoe in 2007. In particular, the BF/BOF route (which uses 13–14 GJ per ton of iron produced) is much more energy-intensive than the scrap/EAF route (using 4–6 GJ per ton of iron produced when using 100% scrap [1]. Given its heavy dependence on fossil fuels, it also accounts for 15% of total anthropogenic GHG emissions [2]. The greenhouse gas of highest relevance to the world steel industry is carbon dioxide (CO_2): 1.9 tons of CO_2 are emitted per ton of steel produced and approximately 4–5% of total world CO_2 emissions are attributed to this sector [3].

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Nomenclature

Abbreviations

ACO	ant colony optimisation
BF	blast furnace
BFG	blast furnace gas
BOF	basic oxygen furnace
BOFG	basic oxygen furnace gas
CC	continuous casting
COG	coke oven gas
DB	database
DSS	decision support system
EAF	electric arc furnace
ESP	electrostatic precipitator
ETS	emission trading scheme
EU	European Union
EUA	European Union Allowance
GA	genetic algorithm
GHGs	Greenhouse Gases
HM	hot metal
HRM	hot rolling mill
IEA	International Energy Agency
KPI(s)	key performance indicator(s)
LF	ladle furnace
LHV	lower heating value
LP	Linear Programming
LS	liquid steel
MILP	mixed-integer linear programming
MIND	method for analysis of INDustrial energy systems
MOO	Multi-Objective Optimisation
PCI	pulverised coal injection
PSO	Particle Swarm Optimisation
SQL	structured query language
VD	vacuum degasser

Parameters, functions and variables

$f(\underline{x})$	objective function of the profit (€/h)
$g(\underline{x})$	objective function of the CO_2 emissions
$\underline{x}$	vector of optimisation variables
$\underline{\underline{A}}$	constraints matrix
$\underline{b}$	constant of the limits or bounds
i	index for process gas producer (1,...,4)
j	index for process gas consumer (1,...,8)
P	time step or period for the optimisation problem
ρ_i	gas produced by the ith producer (GJ/h)
d_j	gas energy demand by the jth consumer (GJ/h)
x_{ij}	gas produced by the ith producers and consumed by the jth consumer (GJ/h)
C_i	set of consumers linked to the ith producer
P_j	set of producers linked to the jth consumer
ε	parameter for the ε-constraint method
lb	lower bound
ub	upper bound
k	index for variation of the ε parameter
m	total number of iterations for the ε constraint method

European and non-EU governments require concrete actions to tackle global warming worldwide [4,5]. Thirty-eight countries committed in December 2011 that a universal legal agreement on climate change should be adopted no later than 2015. Starting from January 2013, a second Kyoto Protocol commitment period will take place [6].

In such a scenario the steel industry is strongly interested in reducing its energy consumptions as well as its CO_2 emissions. The final objective of this research work is therefore to develop and implement a decision support tool aimed at the reduction of the CO_2 emissions and the energy consumptions within an integrated steelwork located in Piombino, Italy.

This steelwork belongs to Lucchini S.p.A., one of the most important Italian integral-cycle steel producers. European leader in long products in special steel and high quality steel for a long time, currently Lucchini S.p.A. is one of the major global players in the industry. The Piombino plant has a production capacity of 2.5 million tons of steel/year. The specific energy consumption of the plant is of about 17.8 GJ/ton liquid steel. This figure has been obtained considering a system boundary that includes the main sub-plants (BF, coke ovens, steel plant, CC, HRM) and considers power plants as external users of process gas, as shown in Fig. 1, where the most important fuel and material flows within the plant are shown. Moreover, fuel as well as electricity is considered as energy inputs while the only outputs that reduce the specific energy consumption are process gases and tar. The difference between our figure and the IEA values can be attributed to a different definition of the system boundaries, which heavily affects the values of energy consumption, as reported by Tanaka in [7,8]. However, the calculated value is more in line with the one obtained in different sources which report energy consumption ranges varying from 16 to 23 GJ/ton LS depending on the chosen boundaries [9,10]. The Lucchini steelwork produces steel according to the oxygen process route with BF and BOF but without a sinter plant.

The management of such complex systems can find assistance in decision support tools which are able to give advice for an optimised operation of the plant, considering different aspects such as, for instance, environmental, economical and energy-related issues. Such a support also responds to the need for new holistic energy and resource management systems that are underlined in the roadmap of a Public–Private Partnership launched by the European Union in 2012 and entitled Sustainable Process Industry (SPIRE) to reach the "Vision 2030" for the European process industry [11]. Different tools for the decision making support in plant management are described in the literature. The possibility to combine flowsheeting models and multi-criteria decision support systems for implementing recycling measures in the iron and steel industry has been discussed in [12,13]. The determination of an optimal blending of residues was also investigated in [14] by considering material composition and market prices to carry out sensitivity analyses. Process flowsheets global optimisation and multi-criteria process analysis and synthesis for a parallel economical and sustainability evaluation are presented in [15,16]. The interaction between different plants in order to integrate transportation planning measures and recycling rates as well as resource and energy efficiency measures have been investigated in [17,18], while an application of a software system for the energy management in the tertiary sector is described in [19]. Several industries have been modelled and analysed using also the MIND (Method for analysis of INDustrial energy system) method: Karlsson [20] uses this method in order to model and analyse two different industries such as a dairy and a pulp and paper mill. Thollander et al. [21] in their paper explore and emphasize not only the systems analysis using reMIND software as investment decision support but also whether investment decision support practices may be used successfully towards small and medium sized manufacturers in Sweden.

A key issue arises when decision support embeds tools for process optimisation: although flowsheeting modelling is well-suited