Available online at www.sciencedirect.com
SCIENCE DIRECT®
Applied Thermal Engineering 26 (2006) 1353–1361
APPLIED THERMAL ENGINEERING
www.elsevier.com/locate/apthermeng

Development of a method for analysing energy, environmental and economic efficiency for an integrated steel plant

Mikael Larsson *, Chuan Wang, Jan Dahl

Division of Energy Engineering, Luleå University of Technology, 971 87 Luleå, Sweden

Received 4 May 2005; accepted 8 May 2005
Available online 24 August 2005

Abstract

The steel industry has faced several challenges during the years. There has always been an aspiration towards higher economic profitability for the system. During the mid 1970s and 1980s the energy crises caused a dramatic rise in energy costs, which led to an increased awareness in energy conservation. In recent years, climate change issues have become more important for the industry. The operating practises for an industrial system are often affected by external restrictions concerning the economical, energy and environmental efficiency of the system. There are a large number of ways to increase the system efficiency, e.g. installation of new process equipment, and practice changes. However, industrial systems such as an integrated steel plant consist of a system of several processes connected together with product and by-product interactions, where changes in one unit may result in changes throughout the total system. A process integration method focusing on the total integrated steel plant system by a simultaneous approach is adopted. An optimisation model is developed and used to study the effect of changes in the existing material and energy system. Applications of the model on the energy and material system have been made. The model can be used to analyse energy, environmental and economic aspects making it a powerful complement as a decision making tool. Conclusions about energy, environmental and economic effects are presented.

Keywords: Process integration; Modelling; Optimization; Steel industry; Energy use; CO_2 emission

1. Introduction

In recent years, increased attention has been given by the steel industry to use energy more efficiently. Steel industry is one of energy-intensive industries, with high CO_2 emissions from the production. Improvement of the energy efficiency, to reduce the energy consumption, will increase the economic profitability as well as reducing the environmental impacts. With increasing concerns of climate change issues, more efforts are made by the steel industry to reduce its CO_2 emission.

Steel production today can be divided into two main process routes: the integrated plant with the blast furnace/basic oxygen furnace (BF/BOF route) and the electro steel plant with the electric arc furnace (EAF route). In 2002, the BF/BOF route accounted for nearly 60% of the world steel production. The EAF accounted for 34% and the rest, 6%, was produced in other processes [1]. Both energy use and the source of energy and raw materials in steel production vary between the two routes. According to the Swedish Energy Agency [2], the energy use in the iron and steel industry accounted for 15% of the total energy use in the Swedish industry. Obviously small efficiency changes in these industries could result in large absolute energy savings. Several studies are available on calculation of the specific energy use and CO_2 emissions from steel production and improvement

* Corresponding author. Present address: MEFOS—Metallurgical Research Institute AB, Box 812, SE- 97125 Luleå, Sweden. Tel.: +46 920 201925; fax: +46 920 255832.
E-mail address: mikael.larsson@mefos.se (M. Larsson).

1359-4311/$ - see front matter
doi:10.1016/j.applthermaleng.2005.05.025

Nomenclature

BF	blast furnace	HM	hot metal
BOF	basic oxygen furnace	LS	liquid steel
CBP	cold bonded pellet	MILP	mixed integer linear programming
CC	continuous casting	MSB	mill scale briquette
CHP	combined heat and power plant	PCI	pulverised coal injection
CO_2	carbon dioxide	PI	process integration
DRI	direct reduced iron	SEC	specific energy use
EAF	electric arc furnace	tHM	tonne of hot metal
GJ	Giga Joule	tLS	tonne of liquid steel
HBI	direct reduced iron	tSlab	tonne of slab

possibilities, e.g. Fruhan et al. [3], Worrell et al. [4,5], Petela et al. [6] and Olynyk et al. [7]. In these studies the steel industry processes and the steel industry branch are studied in general.

As an integrated system, a change of practice in one unit influences the behaviour, e.g. energy and material consumption of other units. It is therefore of interest to optimize the use of energy and raw materials for the total system by using a systematic approach. Several kinds of methods (here named process integration techniques, PI) have emerged for creating general models for global optimization. When process integration emerged as a scientific field, it was almost exclusively concerned with heat integration. Since then, the scope of process integration has widened to include a larger number of aspects, a more thoroughly definition of process integration can be found by IEA [8]. The most commonly used methodologies for process integration are Pinch Analysis, Exergy Analysis and Mathematical Programming. In this paper, the PI technology used is the mathematical programming method based on the mixed integer linear programming (MILP) approach. In a review article by Grossmann et al. [9], an overview of the main concept and applications in mathematical programming can be found.

The method, which allows for both economical and environmental analysis possibilities for an integrated steel plant, is presented. In this paper, actual applications of the method to the material and energy network of an integrated steel plant, which have been preformed and presented in various publications, are summarised. The possibilities of using this method are discussed and general conclusions from these studies are presented.

2. Development of a process integration tool for the steel industry

The model developed in this work is based on a previous model designed for SSAB Tunnplåt AB in Luleå (SSAB) Fig. 1. The main processes in the steel production chain at SSAB, i.e. coke oven plant, BF, BOFs and CC (continuous casting) units, are modelled separately and are connected by primary product interactions (coke, HM, and LS) and by-product interactions. The steel demand from the CC units will determine the LS demand from the BOF, which in turn will determine the HM production from the BF and so forth. The material use is based on the process requirements for each sub-process. The different processes included and the main process flows in the model are shown in Fig. 2. The model core is an overall mass- and energy balance for the production chain and separate sub-balances for the main processes which makes it possible to perform a total analysis for the steel plant and to assess the effect of a change in the operation practice for the different processes. The standard way of operation

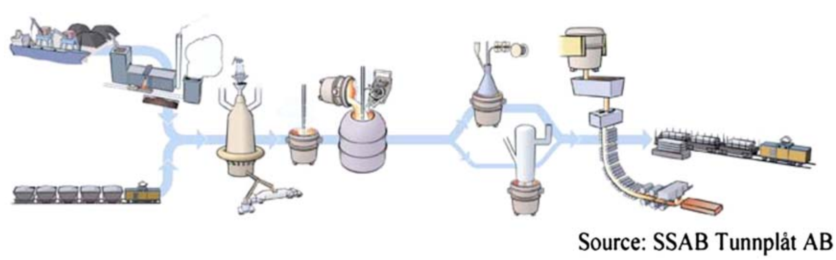

Fig. 1. Schematic process layout of the SSAB steel mill. Processes in the figure, from left to right: coke oven plant, blast furnace, de-sulphurisation plant, BOF converter, secondary metallurgy processes and refining units, CAS-OB and RH vacuum degassing unit, continuous slab caster.