Long term energy efficiency improvements in the iron and steel industry

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1. SYNOPSIS

The long term potential of energy efficiency improvements in the iron and steel industry is determined using a standard methodology.

2. INTRODUCTION

A better understanding of the potential of energy efficiency improvements is important for allocation of R&D-funds and global change response strategies. While the short term potential has been well-studied and is more or less agreed upon, there are differing opinions about the long term potential. This paper forms part of a larger study aimed at developing and testing a methodology to determine the long term potential of energy efficiency improvement in industry (see Beer et al. 1993). The focus of this paper is the iron and steel industry (Beer 1994).

The methodology starts with an energy analysis of a selected steel making process. This step aims to determine the minimum energy required for each process, and the energy losses that occur in these processes. This step is described in section 3. Subsequently, in section 4 an inventory is made of technologies that might reduce these losses. These technologies can be adaptations of the current technologies or completely new technologies. In section 5 a comparison of the selected technologies based on a set of determinants of technological development is made.

3. PROCESS ENERGY ANALYSIS

The two dominating routes for the production of steel are the Blast Furnace - Basic Oxygen Furnace (BF-BOF) route and the Electric Arc Furnace (EAF). The first route involves the reduction of iron ore with coke in the blast furnace. The carbon in the resulting pig iron is oxidized in the basic oxygen furnace using oxygen. The steel that is produced is called primary steel, in contrast to secondary steel that is produced in electric arc furnaces out of steel scrap. Approximately 57% of the world's steel is produced in BF-BOF processes, and approx. 27% in EAF (IISI 1990). The remainder can be accounted to the less energy efficient Open Hearth process, which is the predominant production process in Eastern European and some other countries. As the BF-BOF route is the major production route, this will be the focus of our analysis.

The specific energy consumption (SEC) of an efficient integrated steel plant (Hoogovens, the Netherlands) is 19.7 GJ/tonne steel products [Worrell et al, 1993]. It must be emphasized that the SEC depends on the mix of steel products. The thermodynamical minimum energy demand for the reduction of iron ore (hematite) of 6.2 GJ/tonne, suggests a large theoretical potential.

We performed an exergy analysis of a BF-BOF steel plant based on a reference plant described by IISI (IISI 1982). The results of the exergy analysis are presented in table 1 (Ros 1994).

Table 1. Exergy analysis of the production of continuous cast hot milled steel according to the BF-BOF route (exergy losses in GJ/tonne). Total exergy input is 22.6 GJ/tonne. Exergy losses are defined as the difference between the exergy input and output of a process. Exergy efficiency is defined as the quotient between exergy output and input of a process. The useful exergy output of the steel products is 6.6 GJ/tonne. Other useful outputs, e.g. coke oven gas, BOF-gas and coke breeze, represent 3.2 GJ per tonne.

Process	Exergy loss	Exergy efficiency	Process	Exergy loss	Exergy efficiency
1. Coke ovens	2.1	91%	6. Continuous casting	1.4	83%
2. Sinter plant	2.2	22%	7. Reheating furnace	0.7	91%
3. Hot blast stoves	0.8	54%	8. Hot strip mill	0.9	88%
4. Blast furnace	2.3	84%	9. Central boiler house	1.8	35%
5. Basic oxygen furnace	1.0	90%	Total	12.8	43%

The largest exergy losses occur in the coke oven, the sinter plant and the blast furnace. The coke oven is very efficient. The large losses are caused by the large exergy input. The losses in the sinter plant are mainly heat losses. The low efficiency suggests that there is still large room for improvement. The blast furnace, on the other hand, is already relatively efficient. The major part of these losses are due to upgrading the iron ore to iron.

4. LONG TERM ENERGY EFFICIENT TECHNOLOGIES

Many energy efficient technologies are conceivable. In the short term a reduction from 19.7 to 16.8 GJ/tonne crude steel is technically feasible at Hoogovens, the Netherlands (Worrell et al 1993). We selected four categories of long term energy efficient technologies.

Several advanced iron making processes have been developed or are under development. The smelting-reduction processes seem to be the most promising. These processes avoid the use of coke and pretreated iron ore. In principle smelting-reduction involves the combination of a coal gasifier and a convertor. Examples are COREX, CCF, HIsmelt, DIOS, and the AISI process (see e.g. Fulkerson 1989).

Direct steel making is aimed at the production of steel directly from ore, thus eliminating the intermediary iron production. Only one description of such a process has been found in literature (Fulkerson 1989). It involves magnetic separation and chemical leaching. No smelting is required. However, this process is still in a very early stage of development.

Direct casting (also near net shape casting) is casting of the hot metal directly from the steel making process into shapes that approximate those of the final products. State-of-the-art is thin-slab casting. Strip casting and spray casting are under development (see e.g. Stelco 1993).

A technology that involves changing of the process route is increased recycling of iron scrap and subsequent processing in electric arc furnaces. This results in the elimination of the iron ore preparation and reduction in the blast furnace. Account should be made for the higher energy demand and costs for scrap upgrading, because of the contamination with residual elements. On the other hand, the efficiency of electric arc furnaces will increase, for instance by the development of ultra high power furnaces.

Besides these technologies, several other technologies are under development, e.g. direct reduction (based on the principle of generating a reducing gas by a chemical reaction between the off-gas and a carbonaceous fuel) and reduction with hydrogen. Although these technologies have advantages, e.g. costs reduction, the energy demand is probably not lower than that of the BF-BOF-route.

5. COMPARISON OF ENERGY EFFICIENT TECHNOLOGIES

Because no operational data are available, only an estimate can be made of the energy demand of new technologies. The lowest energy demand can be achieved when only secondary steel is produced in a highly efficient EAF. We estimate this at 6 GJ/tonne primary energy, including additional energy required for scrap upgrading. With the selected technologies the SEC for primary steel making can be reduced to 11 to 14 GJ/tonne. Efficient casting and shaping technologies are also incorporated in these figures. Optimization and integration of all conceivable efficient technologies might further reduce the SEC.

To assess the possible development of new technologies, other parameters than energy efficiency should be considered, too. An overview is given in table 2.

Table 2. Overview of parameters that might influence the development of the selected technologies

Technology	State-of-the-art	Barriers	Research institute
HE EAF with increased recycling	laboratory scale	-development of high capacity plasma arcs -scrap upgrading	-steel manufacturers; -sector related institutes
Plasmamelt	demonstration (for FeCr)	-development of high capacity plasma arcs	-multinational non-sector related company (SKF Plasma Technology (S))
Iron ore smelting	demonstration	-increasing in-reactor CO-utilization and/or post-combustion; -decrease sulfur content in coal;	-steel manufacturers (e.g. Kawasaki Voest-Alpine; Hoogovens; ISCOR); -sector related institutes (e.g Japan Iron and Steel Federation);
Spray casting	pilot plant for 3 mm thickness	-low yield because of need to overspray	-sector related institute (Mannesmann Demag)
Strip casting	prototype (max 1.0 mm thickness)	-geometry of the strip -surface quality -physical properties	-steel manufacturers (e.g. Nippon Metal, Thyssen Stahl); -sector and non-sector related research) institutes (e.g Armco/ Westinghouse)
Ore-to-powder process	fundamental research	-development of highly refined magnetic separation	-research laboratory (Pacific Northwest Laboratory)

6. CONCLUSIONS

Most probably the future primary steel plant will be a compact plant, without coke production and ore preparation plants, with a smelting-reduction ore reduction process and direct casting, making rolling operations redundant. At this moment it is not possible to say which technologies will dominate the market. The specific energy demand will be in the order of 11 to 14 GJ/tonne finished steel (an efficiency improvement of 30 to 45% compared to the current best practice process).

7. ACKNOWLEDGMENTS

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8. REFERENCES

Beer, J.G. de, E. Worrell, and K. Blok. 1994. "Energy Efficiency Improvement on the Long Term: Case Study: Paper and Board Industry." Proceedings of the 2nd European Congress on Economics and Management of Energy in Industry. ECEMEI, Lisbon.

Beer, J. de. 1994. Long Term Energy Efficiency Improvements in the Industry. IIASA, Laxenburg, Austria (to be published).

Fulkerson, W. (Study Leader). 1989. Energy Technology R&D: What Could Make a Difference?, Volume 2, part 1 Oak Ridge National Laboratory, DOE, Washington.

IISI. 1990. Steel Statistical Yearbook. International Iron and Steel Institute, Brussels.

IISI. 1982. Energy and the Steel Industry. International Iron and Steel Institute, Brussels.

Ros, T. 1994. Exergy Analysis of an Integrated Steel Plant. Department of Science, Technology and Society, Utrecht University, The Netherlands.

Stelco Research and Development Department. 1993. Present and Future Use of Energy in the Canadian Steel Industry. Efficiency and Alternative Energy Technology Branch, CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario.

Worrell, E., J. de Beer and K. Blok. 1993. "Energy Conservation in the Iron and Steel Industry." Pilavachi, P.A. (ed.).Energy Efficiency in Process Technology Proceedings of the International Conference, held in Athens, Greece 19-22 October 1992. Elsevier Science Publishers, London.