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Research Paper

Potential for energy savings by heat recovery in an integrated steel supply chain

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HIGHLIGHTS

- The potential for energy savings of an average steel mill is estimated.
- Pinch analysis is used to optimise an integrated network of heat exchangers.
- Proposed networks may save up to 3.0 GJ per tonne of hot rolled steel.
- Limited savings may be obtained from the integration with other industries.

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ABSTRACT

Heat recovery plays an important role in energy saving in the supply chain of steel products. Almost all high temperature outputs in the steel industry have their thermal energy exchanged to preheat inputs to the process. Despite the widespread development of heat recovery technologies within process stages (process heat recovery), larger savings may be obtained by using a wider integrated network of heat exchange across various processes along the supply chain (integrated heat recovery). Previous pinch analyses have been applied to optimise integrated heat recovery systems in steel plants, although a comparison between standard process heat recovery and integrated heat recovery has not yet been explored. In this paper, the potential for additional energy savings achieved by using integrated heat recovery is estimated for a typical integrated steel plant, using pinch analysis. Overall, process heat recovery saves approximately 1.8 GJ per tonne of hot rolled steel (GJ/t hrs), integrated heat recovery with conventional heat exchange could save 2.5 GJ/t hrs, and an alternative heat exchange that also recovers energy from hot steel could save 3.0 GJ/t hrs. In developing these networks, general heat recovery strategies are identified that may be applied more widely to all primary steel production to enhance heat recovery. Limited additional savings may be obtained from the integration of the steel supply chain with other industries.

1. Introduction

The steel industry operates at some of the highest temperatures of all industrial processes and the whole supply chain involves multiple cycles of heating and cooling. These high temperatures are fundamental to the operation of the supply chain—either to enable the reduction of iron ore into iron, to alter the microstructure to improve product properties, or to soften the metal so it may be formed to the desired shape. These several high temperature processes result in significant energy losses in hot output flows.

Heat exchangers may be implemented to transfer thermal energy from hot output flows into a cold incoming flow, reducing the burden of external fuel required for heating and so improving energy efficiency. Technologies exist for heat recovery from most of the hot outputs in the supply chain, but have been developed with a focus on each individual process stage, where the energy transfer occurs between the outputs and inputs of the same process (*process heat recovery*). However, *integrated heat recovery*, where a series of processes are considered together and outputs of one process are linked to inputs of another, may allow for a larger energy saving through better matching of hot and cold flows. The substantial distance between process units limits the affordability of unrestricted heat exchanging, particularly when applied to existing plants and their operating constraints. In this paper, the method of pinch analysis is used to estimate the potential for additional savings through implementing integrated heat recovery across all processes in the primary steel supply chain. This analysis is applied to a generic steel plant in design phase, thus not subject to limitations associated with the location of existing equipment.

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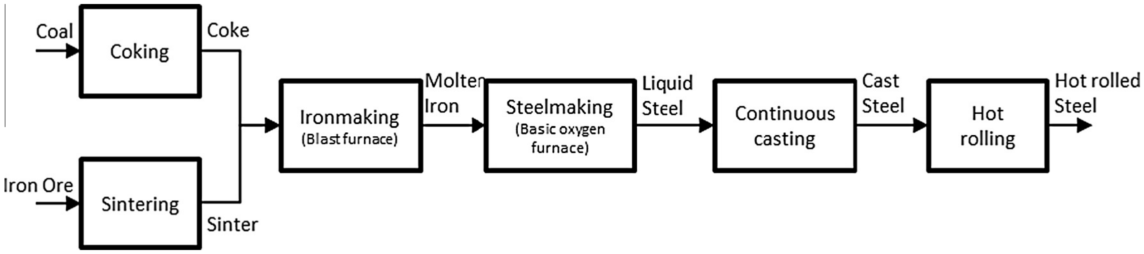

Fig. 1. Overview of supply chain for primary steel production.

1.1. Processes in primary steel production

Primary steel production involves the reduction of sintered iron ore with coke in a blast furnace (BF) and subsequent treatment in a basic oxygen furnace (BOF). This is distinct from secondary steel production, in which scrap is remelted in an electric arc furnace. In primary production, molten steel output is typically continuously cast and hot rolled to make a range of stock products that are sold for subsequent fabrication into consumer products. These fabrication steps are frequently carried out cold and therefore have no potential for heat recovery, so are not included in this analysis. An overview of how the processes in primary steel supply chain are linked is given in Fig. 1, and the changes taking place in each process are described below. The processes are described in more detail by IISI [9].

Cullen et al. [6] calculate global mass flows through the steel supply chain from a range of data sources. The supply chain shown in Fig. 1 covers 95% of all steel production.

The energy required to manufacture steel products is commonly quoted as a sum of the energy inputs to each process in the supply chain divided by the mass of steel in the product. In this paper, the unit gigajoules of primary energy per tonne of hot rolled steel product (henceforth GJ/t) is used. Where necessary, electricity or final energies are denoted by the subscripts GJ_e/t, and GJ_f/t respectively. A lower energy consumption per tonne of steel indicates a more efficient supply chain.

Through an industry survey of 16 sites, IISI [9] have calculated an average energy consumption of 19.2 GJ/t for primary steel production in the BF-BOF route described in Fig. 1. A range of process heat recovery options are included, although they are implemented to varying degrees across the different sites surveyed. A more recent survey by Worrell et al. [15] combines the lowest reported process energy consumptions to define best practice for hot rolled steel as 18.2 GJ/t via a similar process route, down to 16.3 GJ/t using thin slab casting to integrate casting and hot rolling. Best practice includes implementation of all commercially viable heat recovery technologies. De Beer et al. [2] estimate available heat energy across the whole supply chain as 5.5 GJ/t (Table 13, pp. 189) with a significant proportion recoverable, so an energy consumption of over 20 GJ/t would be expected with no heat recovery at all. Various process heat recovery technologies are described for each of the hot output flows, and are summarised in Table 1.

Some general trends in process heat recovery are observed. The use of recuperative or regenerative heat exchangers for heat recovery from hot exhaust gases are common across all processes and widely applied. In addition to thermal energy, some gaseous outputs have chemical energy that may be recovered via combustion, and dry cleaning of the gas must be employed in order to recover both the thermal and chemical energy. The granulated solid outputs (sinter, coke, and slag) are all used to preheat air, which may be taken as a direct input to combustion, or undergo a further heat exchange step to preheat an input. Heat recovery from solid steel is rare, with only isolated examples quoted in the literature. A separate strategy exists where the output product of one process is not allowed to cool, thus carrying the heat to the following process, for example taking molten iron from the blast furnace for

Table 1
List of hot outputs from the steel supply chain with potential heat recovery methods currently available and average energy saving obtained if implemented. Data compiled from IISI [9] except where noted.

Process	Output	Temp (°C)	Thermal energy (GJ/t)	Other energy[a] (GJ/t)	Heat recovery method	Energy saving[c] (GJ/t)
Coking	Coke oven gas	700	0.18	0.69	District heating	0.13[d]
	Coke	1100	0.55	–	Coke dry quenching to generate steam	0.59
	Flue gas	250	0.10	–	Fuel preheating	0.04
Sintering	Sinter	700	0.88	–	Dry cooling – preheated air input	0.32
	Stack exhaust	350	0.34	–	Recirculation	0.19
Ironmaking	Blast furnace gas	180	0.32	4.12	Dry cleaning and top recovery turbine	0.19
	Blast stove exhaust	250	0.06	–	Incoming air preheat	0.10
	BF Slag	1500	0.49	–	Dry granulation – air used to generate steam	0.21[b]
Steelmaking	BOF exhaust	1700	0.18	0.13	Waste heat boiler to generate steam	0.19
	BOF Slag	1700	0.05	–	Dry granulation – air used to generate steam	0.00
Casting	Steel	1200	0.70	–	–	–
	Steel latent heat	1200	0.27	–	–	–
Hot rolling	Reheat exhaust	700	0.20	–	Recuperative or regenerative burners	0.11
	Steel out	900	0.53	–	Space heating (hypothetical)	0.01
Totals (GJ/t)			4.9	4.9		2.0

[a] Other energy includes chemical energy that may be recovered by combustion and energy stored in high pressure gas outputs.

[b] From Barati et al. [1].

[c] Average energy saving that could be obtained if heat recovery method is implemented. These values are the current average of plants surveyed, which may be different from energy saving obtained in specific state-of-the-art steelworks.

[d] District heating energy saving is used outside the steelworks and consequently it does not affect the overall energy intensity of producing hot rolled steel. Therefore, this potential energy saving is not included in the total potential energy saving presented in the table.