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Process integration of steelmaking and methanol production for suppressing CO_2 emissions—A study of different auxiliary fuels

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ABSTRACT

In this work mathematical programing has been used to study the process economics, carbon dioxide emission and energy flows of a future steel plant which is integrated with a polygeneration plant. The system considered includes an integrated steelmaking plant with conventional or novel ironmaking technologies with top gas recycling and CO_2 stripping, a CHP plant and a methanol plant. Oil, natural gas and biomass are considered as both auxiliary reducing agents in the blast furnace and also as fuel in the polygeneration system. The results illustrate that an integration of steelmaking with a polygeneration system will increase the total energy efficiency and decrease the emissions of the system. It is demonstrated that certain combination of new technologies and alternative fuels yield scenarios with strongly reduced emissions, indicating a path to sustainable development in steelmaking.

1. Introduction

Steel manufacturing is often considered to be an indicator of economic progress because of the critical role played by steel in infrastructural and overall economic development. The economic growth in Asia, particularly in China and India, has caused a massive increase in the demand for steel in recent years, and global steel production hit a record of 1500 million tons in 2011. As for stainless steel, the production may increase at an average annual rate of 10 percent. Besides energy conversion, steelmaking is the largest industrial emitter of carbon dioxide in the world. It can be anticipated that the CO_2 emissions from the steel industry will increase further along with the growth of crude steel production, unless significant changes in the current process route, energy efficiency or some effective CO_2 emission reduction technology can be implemented. Therefore, it is of great importance to develop methods for analysis of CO_2 reduction possibilities in the steel industry, also considering economic aspects, because in sustainable development environmental protection and conservation, social well-being and economic development should be appropriately balanced. To achieve a sustainable steel production, there are approaches to reduce emissions in the short term such, as using more hydrogen-bearing reductants (e.g., natural gas, which reduces the coke consumption and increases furnace productivity) or increasing the energy efficiency of the unit processes. Long-term approaches include the substitution of fossil fuels with non-fossil sources of energy, e.g., biomass, integration of steelmaking with other chemical processes, such as polygeneration system and carbon capturing and sequestration plants, and conceptual design of novel steelmaking routes [1].

Short- or medium-term approaches to reduce the coke rate and the emissions from the system also include the application of new technologies, such as top gas recycling and tuyere injection of cold oxygen. These concepts have been investigated and implemented in pilot and semi-industrial units [2]. Top gas recycling makes it possible to utilize the carbon introduced into the blast furnace more efficiently, thereby decreasing the coke and increasing the production rate. Today, the concept has attracted particular attention due to the possibilities it offers for combination with CO_2 sequestration [3–5]. The residual gases could also be used in a polygeneration system to produce chemical byproducts, heat and electricity [6,7].

As for the use of biomass as a reductant and a source of energy, there have been different studies in iron and steel making, including the use of charcoal. Charcoal is not suitable as a burden (but for mini blast furnace) because of its low strength, but it can be injected through the tuyeres. Ueda et al. [8] have shown that the gasification reaction rate of biomass char is faster than coke gasification and the proper heat treatment of biomass would show the similar combustibility of pulverized coal in raceway. Helle et al. [9,10] have analyzed the process economics of injecting dry biomass into the blast furnace considering cost of raw materials, energy and carbon dioxide emissions. The authors showed that the pre-processing of

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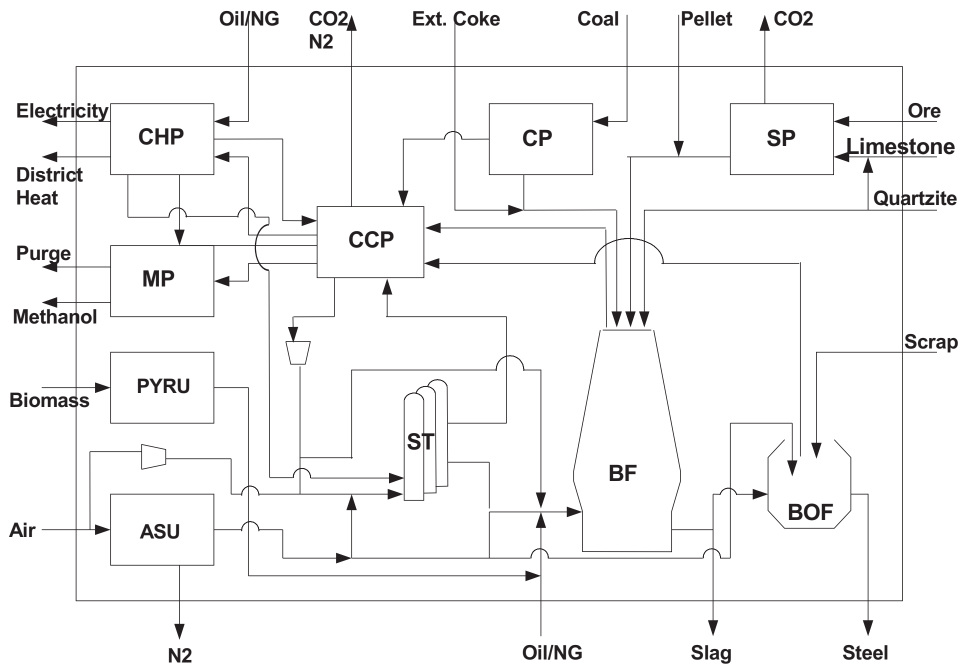

Fig. 1. Integrated steel plant. CP: coke plant, SP: sinter plant, ST: hot stoves, CCP: CO_2 capturing plant, ASU: air separation unit and MP: methanol plant.

the biomass is necessary to achieve high productivity of blast furnace, but that it was not economical to fully convert the biomass to charcoal due to the associated yield loss.

In general, emission reduction strategies are a complex problem due to several dependent and self-determining variables, such as production demand, availability of resources and technologies, energy efficiency, world economic, government and global policies, etc. In this study, mathematical programing has been used to investigate the combination of short- and long-term technologies on energy efficiency and carbon dioxide reduction in steel production. An integrated steelmaking plant is combined with a plant for methanol production, and the process economics are optimized with respect to the unit price of (liquid) steel, considering costs of raw materials, energy, emissions and credits for produced coke, methanol, power and heat. Three options of operating the blast furnace are studied, where two apply top gas recycling with carbon capture and storage, which imposes additional costs. Furthermore, a set of alternative energy sources, i.e., oil, natural gas, and biomass, are used to illustrate how different reductants/fuels could be utilized for the novel production concepts studied.

2. Process descriptions

The system studied in this work is shown in Fig. 1 and it includes an integrated steelmaking plant with coke production, a sinter plant for producing the agglomerated iron ore, a blast furnace for reduction and melting, hot stoves for heating of the combustion air (blast), and a basic oxygen furnace where the liquid iron is converted to steel. Secondary steelmaking units (ladle treatment and casting) as well as the rolling plant are left outside the present study. Furthermore, the system includes a combined heat and power (CHP) plant producing district heat and electricity. The above mentioned units are modeled in accordance with the conditions at a Finnish reference plant, which also specify the constraints to be imposed in the numerical treatment [9,11]. In addition to these conventional units, an air separation unit, a carbon capturing and sequestration unit, a biomass pyrolysis unit (optional) and a methanol synthesis plant are included in the system of this study.

2.1. Iron feed

One of the first processes involved in primary steelmaking is the sinter plant which converts a raw material mixture, with iron oxides as main constituent, into agglomerated particulate form, sinter, which is fed to the blast furnace. A bed of sinter feed mix travels under an ignition hood where hot combustion gases ignite coke blended into the sinter mix to start the sintering process, which is maintained by sucking large volumes of air through the bed from below. Therefore, the process is a source of CO_2 emissions that can be estimated from mass balance of the sinter plant. In the steelmaking plant studied in this paper, the sintermaking capacity is limited, so external iron bearing materials may be needed in order to reach the desire steel production rate. Pellets from an external producer will be used in the system in range of 0–600 kg/t hot metal if required.

2.2. Cokemaking

In the coking operation coal is dry-distilled to coke, which is a strong particulate matter of low reactivity at moderate temperatures suitable as a feed to the blast furnace. Cokemaking products are coke, coke oven gas (COG), tar and residual fuel oil. The main part of the coke goes to the blast furnace, while a smaller amount of coke breeze goes to the sinter plant. For practical reasons the capacity of coke production is considered to be fixed at the upper limit (here 55 t/h), so any deficit/excess of coke (after the requirement of the sinter plant and blast furnace) will be bought/sold.

2.3. Reduction and smelting

Pig iron is produced by the reduction of agglomerated iron oxide ores in a blast furnace. The combustion of coke, which is maintained by the supply of preheated air (blast), provides carbon monoxide to reduce iron oxides to iron and provides additional heat to melt the iron and impurities. Carbon dioxide emissions are produced as the coke and auxiliary injected reductants (e.g., pulverized coal or oil) are oxidized. Furthermore, CO_2 emissions arise through the decomposition of carbonate fluxes added, because calcium and