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Evaluation of low and high level integration options for carbon capture at an integrated iron and steel mill

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ABSTRACT

To achieve climate goals, the iron and steel industry needs to find energy efficient and cost saving pathways for implementing CO_2 capture. This paper evaluates two integration alternatives of excess-heat powered CO_2 capture at an integrated iron and steel plant using the concept of partial capture. The two sources of CO_2 investigated were the blast furnace gas (BFG) and flue gas from the combined heat and power (CHP) plant, representing a high and low level integration alternative, respectively. An amine capture system was simulated in Aspen Plus, and optimized for low energy requirement. To analyze the effects on the iron and steel system and the level of available excess heat, an in-house model was used containing interlinked energy and mass balances of each process step available. The results show that high level integration of CO_2 capture gives a lower specific heat demand and improves the overall energy efficiency of the steel plant, resulting in more available heat. For this reason, it is possible to capture 3% more from BFG without any extensive alterations to the plant to recover excess heat. The total available excess heat at the plant will sustain capture of up to 46% of the steel plants total CO_2 emissions, and beyond that point steam has to be imported.

1. Introduction

Energy for CO_2 separation and compression make up 70–80% of the cost for carbon capture and storage (CCS) (Leung et al., 2014). Compared to other industries, iron and steel have good possibilities to capture CO_2 at low cost, as it has gas flows with naturally high CO_2 concentration and large amounts of excess heat in the required temperature range (Tsupari et al., 2013). A typical integrated iron and steel plant emits 2 t of CO_2/t steel, utilizes 20 GJ/t steel, and has an average heat recovery potential of around 5.5 GJ/t steel (McBrien et al., 2016). Theoretically, heat recovery could thus supply up to 2.7 MJ heat per kg CO_2 in the range required for CO_2 separation from gas mixes. The heat may be recovered from various process streams at high-temperature (molten slags, process gases, discarded melts) and low-temperature (flue gas, cooling water, process steams, hot steel slabs).

1.1. Steel production in Luleå

More than 70% of the world's steel is produced through the blast furnace (BF) route (World Steel Association, 2015). Fig. 1 shows material and gas flows at SSAB Europe's iron and steel plant in Luleå that operates with a blast furnace burden of 100% iron ore pellets. The iron ore is reduced by carbon and CO, generated from partial combustion of coke and coal in the presence of oxygen-enriched hot air (i.e., the hot blast). The hot blast is heated in the hot stoves (HS) by firing of exiting top gas of the BF and coke oven gas (COG) formed at the coking plant. Besides facilitating the reduction, coal and coke are also required as energy supply. Coke also forms the structural integrity of the furnace to allow internal gas and liquid flows. To remove impurities present in the ore, flux additives, such as limestone and recycled slag from the basic oxygen furnace (BOF), are added into the furnace to form slag. Together with the reduced hot metal, the slag accumulates in the bottom of the furnace where it is separated and tapped in regular intervals.

To be able to produce high strength steels, the tapped hot metal is treated for removal of impurities and addition of alloying elements. In the BOF, oxygen is blown into the hot metal in order for carbon, saturated in the melt, to react and form CO and CO_2, which leave the BOF with the exiting gas. By removal of carbon the hot metal is converted into steel. Similar to the BF, flux additives are added to the batch to remove impurities via a slag that is extracted at the finish of the blow. After the BOF, the steel is alloyed and cast into slabs. As SSAB in Luleå do not have a rolling mill, the steel slabs are transported by train to the

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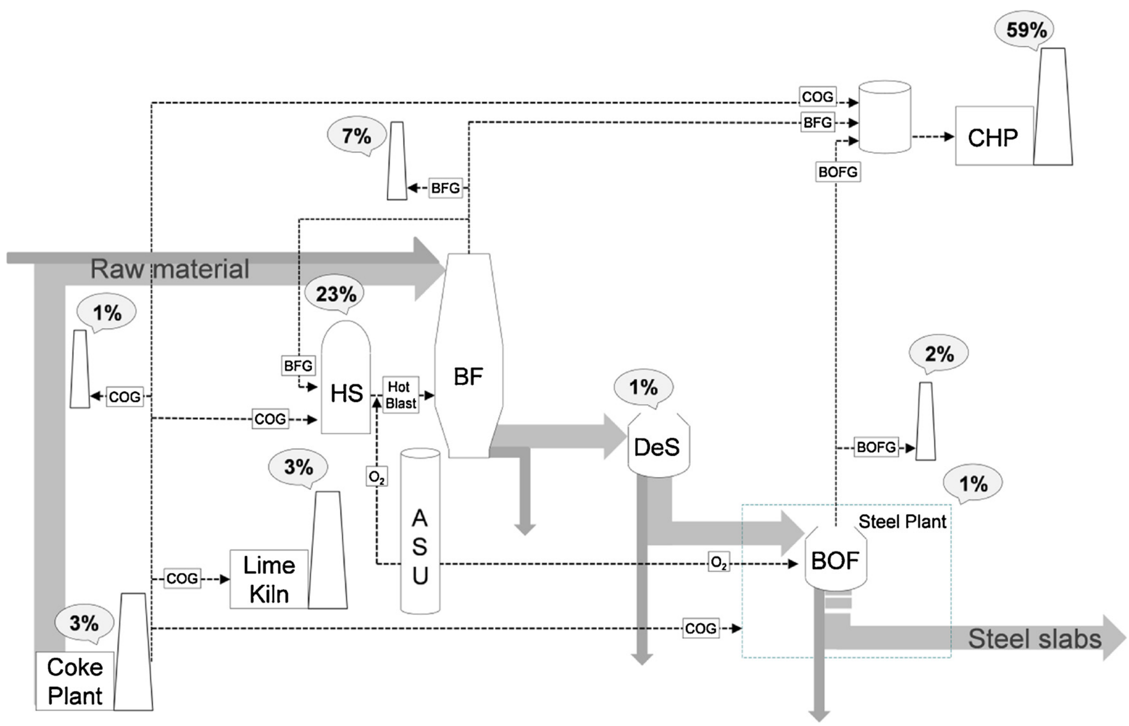

Fig. 1. Material and gas flows throughout SSAB's integrated iron and steel plant in Luleå. Indicated is the share of total CO_2 emission from the site's nine point sources.

southern parts of Sweden for further refinement into steel products. The absence of a rolling mill do free up some of the process gases typically used as fuel for pre-heating of steel slabs in a traditional integrated iron and steel plant. Excess process gas that is not used inside the iron and steel plant for heating or steam production is sent to a nearby combined heat and power (CHP) plant that supplies electricity to the plant, and hot water to the local district heating network.

In an integrated iron and steel system, the interacting process units may operate at different time intervals. Some processes are operated continuously, such as the BF, meanwhile many secondary metallurgy processes are operated batch-wise, such as the BOF. This will cause fluctuations in the gas flow and in the steam production of the system. To reduce these effects, gases and steam produced are stored in gas accumulators. Thus, even as normal fluctuations occur, the gas and steam generation throughout the plant can be perceived as continuous. Flaring of gases in the system usually occur due to disturbances in the system, if the gas accumulators are overloaded or during maintenance stops in the power plant.

1.2. CO_2 capture and steel industry

Bearing in mind that an integrated iron and steel plant has several CO_2 emission stacks (e.g., lime kiln, power plant, hot stove, coke oven), as well as process units (BF, coke oven, and BOF), complete avoidance through CO_2 capture is not technically and economically feasible (Arasto et al., 2013). However, CO_2 capture from individual and major emission point sources can lower the emissions drastically to a feasible cost of capture (Arasto et al., 2013; Ho et al., 2013). The two largest point sources at an integrated iron and steel mill are the exhaust gases from the hot stoves and power plant. At SSAB in Luleå, the two sources together compose over 80% of the CO_2 emissions.

Since 70% of all carbon input to the process (Farla et al., 1995) is introduced as coke or coal to the BF, CO_2 capture in proximity to the furnace is favorable and frequently studied. It is often suggested in combination with other improvements to the BF in order to lower the total carbon input to the process, e.g., top gas recycling of decarbonized BFG back to the BF, meanwhile replacing the hot blast with oxygen (Meijer et al., 2009). Essentially, decarburization of BFG will improve the gas fuel quality, enable its use in, e.g., steam boilers for electricity generation or in heating application at the plant without additional fuel (Gielen, 2003).

1.3. Scope of paper

The aim is to compare integration alternatives of excess-heat powered CO_2 capture at an integrated iron and steel plant using the concept of partial capture. Partial capture implies that the capture process is designed to capture only parts of the CO_2 emissions in order to reduce cost. The amount of CO_2 that will be captured is thereby strongly connected to how well the capture unit is integrated into the steel plant system and the availability of heat.

In this paper, the two most CO_2 intensive gas streams at SSAB's plant in Luleå are analyzed and evaluated. The sources considered are BFG, referred to as the high level integration alternative, and the CHP plant flue gas, denoted as the low level integration alternative. The capture technology considered is capture via monoethanolamine (MEA) absorption which is a well-known, commercial solvent often used in this field of studies as a reference. In contrast to other studies on CCS in steel industry, the heat required by the MEA capture, will only be available through recovery of excess heat. Therefore, this paper will also include a heat analysis, pinpointing heat sources at the plant site and assessing their feasibility according to availability and economic investment.

2. Method

2.1. Case description

Two CO_2 capture cases were evaluated in this paper to determine the system impact of high level compared to low level integration of MEA CO_2 capture, see Fig. 2.

To illustrate low level integration (see point A, Fig. 2), flue gas from