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Biomass as blast furnace injectant – Considering availability, pretreatment and deployment in the Swedish steel industry ☆

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ABSTRACT

We have investigated and modeled the injection of biomass into blast furnaces (BF), in place of pulverized coal (PC) from fossil sources. This is the easiest way to reduce CO_2 emissions, beyond efficiency-improvements. The considered biomass is either pelletized, torrefied or pyrolyzed. It gives us three cases where we have calculated the maximum replacement ratio for each. It was found that charcoal from pyrolysis can fully replace PC, while torrefied material and pelletized wood can replace 22.8% and 20.0% respectively, by weight.

Our energy and mass balance model (MASMOD), with metallurgical sub-models for each zone, further indicates that (1) more Blast Furnace Gas (BFG) will be generated resulting in reduced fuel consumption in an integrated plant, (2) lower need of limestone can be expected, (3) lower amount of generated slag as well, and (4) reduced fuel consumption for heating the hot blast is anticipated. Overall, substantial energy savings are possible, which is one of the main findings in this paper.

Due to the high usage of PC in Sweden, large amounts of biomass is required if full substitution by charcoal is pursued (6.19 TWh/y). But according to our study, it is likely available in the long term for the blast furnace designated M3 (located in Luleå).

Finally, over a year with almost fully used production capacity (2008 used as reference), a 28.1% reduction in on-site emissions is possible by using charcoal. Torrefied material and wood pellets can reduce the emissions by 6.4% and 5.7% respectively. The complete replacement of PC in BF M3 can reduce 17.3% of the total emissions from the Swedish steel industry.

1. Introduction

The scrap-based steelmaking is often highlighted as the future resource-efficient way of producing steel. The emissions-intensive ore-based route still dominates because of a simple fact, the recycled steel cannot yet supply the volume needed worldwide (only about 30% as of now [1]). Therefore, more virgin materials are needed in the loop of recycling and thus it is projected, considering the world population growth; that Blast Furnace (BF) and Direct Reduced Iron (DRI) production will continue to dominate until at least 2050 [1].

Climate change, however, calls for a quicker response. Targets in the European Union (EU) call for a 20% cut in CO_2 emissions, a 20% improvement in energy efficiency and a 20% increase of renewable energy, by 2020. According to EU ambition, an 80% cut should be achieved until 2050, while the Swedish ambition is to cut 100% in *net* CO_2 emissions. This paper addresses the seemingly irreconcilable need for steel and cuts in emissions, by presenting research on how to reduce the footprint of blast furnaces. The idea is to replace pulverized coal (an auxiliary fuel), which is injected in large amounts in Swedish blast furnaces. The needed biomass is found in ample amounts in Sweden and available knowledge suggests that operating conditions will not be fundamentally affected [2–6].

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Nomenclature

Expressions

Top gas temperature	Outlet temperature at the top of a BF
Hot stove	Heat exchanger for preheating the blast *or* hot air
Shaft efficiency	$(\%_{CO_2}/(\%_{CO_2}+\%_{CO}))_{TRZ}/(\%_{CO_2}/(\%_{CO_2}+\%_{CO}))_{equilibrium}$

Abbreviations

BF	Blast Furnace
BFG	Blast Furnace Gas *or* Top gas
CFD	Computational Fluid Dynamics
COG	Coke Oven Gas
DRI	Direct Reduced Iron
EU	European Union
RAFT	Raceway Adiabatic Flame Temperature (°C)
HM	Hot Metal *or* crude iron
tHM	ton of Hot Metal (t)
HTC	Hydrothermal Carbonization
LCA	Life Cycle Assessment
LHV	Lower Heating Value (MJ/kg)
M2	Masugn 2, blast furnace in Oxelösund
M3	Masugn 3, blast furnace in Luleå
M4	Masugn 4, blast furnace in Oxelösund
PCI	Pulverized Coal Injection
SE	Steam Explosion
Eta CO	Gas utilization efficiency $\%_{CO_2}/(\%_{CO_2}+\%_{CO})_{theoretical}$
TRZ	Thermal Reserve Zone

Roman letters

C	Carbon content (%wt)
H	Hydrogen content (%wt)
h	hour
N	Nitrogen content (%wt)
O	Oxygen content (%wt)
S	Sulfur content (%wt)
T	Temperature (K)
t	ton (1000 kg)
y	year
W	Watt (J/s)

As such, this study aims to investigate the simplest application of biomass, to give a realistic replacement potential in the near future. Availability of biomass is another concern, which could prohibit the, more challenging, substitution of all fossil fuel in the steel industry. The considered pretreatments (carbonization, torrefaction and pelletization) are used from the outset as scenarios. For each pretreatment, the maximum replacement ratio is calculated, in addition to the effect on operating conditions (see Sections 3.1 and 4.1 for methodology and results respectively), then the needed biomass versus the available biomass is estimated (see Sections 3.2 and 4.2) and finally the corresponding maximum reduction in CO_2 emissions are estimated (see Sections 3.3 and 4.3).

This introduction is followed by a background, which covers motive and the previous work in this field. A methodology section describes how this study is carried out and Section 4 describes the results, followed by Section 5—the conclusions.

2. Background

Efforts to reduce CO_2 emissions in Sweden have been refocused, from generating renewable power and district heating, to supplying renewable fuels for industry and transportation. The steelmaking sector in Sweden is a large contributor to emissions, which calls for a concentrated effort, but it is by far not the simplest case where renewables may be introduced. The reason is a lock-in effect, which stems from long investments in fossil-based technology, but also energy saving measures. Integrating the steel production (e.g. using Coke Oven Gas (COG) as fuel-supply in other parts of the plant) results in better energy efficiency, but at the same time moves the industry further away from renewable alternatives. The main contributor is the blast furnace, which uses coal and generally dominates in terms of emissions and energy consumption [7].

Using biomass is one method to combat the emissions. In fact, biomass from the boreal forest has historically been used for steelmaking and contributed in the 18th century to propel Sweden to the top steelmaking nations worldwide. The later use of coal was almost universally adopted during the industrial revolution. Coke (coal treated in a coking process) overtook biomass as a reduction agent in iron making from: 1760 in Britain [8], 1835 in Belgium [8], 1853 in France [8] and at the beginning of the 20th century in Sweden [9]. The superior properties of Coke as bed material, enabled the large and efficient types of blast furnaces used today. The Swedish blast furnaces are listed in Table 1, which are many times larger than the older type. The general understanding is that large blast furnaces cannot function properly with raw or pretreated biomass as bed material. The main constraint is the low compression-strength of biomass at high temperatures, which impairs the passage of gases through the shaft.

Over the years, injection of pulverized coal (PC) has been introduced worldwide in the majority of all blast furnaces [2]—foremost as a cost saving measure. A previous study by some of the authors; Orre et al. [12], investigates the economic impact of introducing a range of injectants, where injections clearly lower the production cost versus an all-coke operating mode. Though, this practice might now pave the way of using significant portions of biofuel. Of the different streams of fossil fuel to the blast furnace, replacing the injection is understood as the easiest way to introduce biomass [2–6]. Thus, in Sweden, the carbon footprint of blast furnaces is possible to reduce significantly and since Sweden has abundant forest resources, favorable conditions exist for companies to pioneer this method.

With recent developments, the blast furnaces in Sweden can now operate with a comparably low total reductant rate, mainly due to large furnace volume and a large portion of high-quality pellets. The low coke rate of 320 kg/tHM (for BF M3 in Table 1) is usually not achieved unless a very high PC rate is used (200–230 kg/tHM according to Babich et al. [13]). As seen in Table 1, the PC rate for BF M3 is 135 kg/tHM, which is at the lower end of the European average (130–150 kg/tHM according to Lacroix et al. [14]). Thus, the CO_2 emissions are by comparison already low and the possibility of adding varying amounts of biofuels and changing the ratio of coke and coal, gives significant flexibility to balance economics and emissions. Norgate and Langberg [3] investigate the optimal balance, which is directly affected by emission caps and carbon tax. As the caps decreases and taxes increase, flexibility is key to competitive steelmaking. Note that the 2008 numbers for coal and coke rate, which are slightly different, is used in the simulation (155 and 305 kg/tHM respectively), total reductant rate is nearly unchanged however.