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PROCESS SIMULATION OF BLAST FURNACE OPERATION WITH BIOMASS SYNGAS INJECTION FOR CLEAN PRODUCTION

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ABSTRACT

The modern steel industry depends largely on blast furnace route to produce hot metal. Massive amount of CO_2 is discharged in the blast furnace process through utilising carbon-based reducing agents e.g. coke to extract iron from iron ore. It is extensively acknowledged that renewable and biomass-generated reducing agents are gathering momentum to replace part of coke in ironmaking applications. Syngas produced from biomass gasification is mainly composed of hydrogen and carbon monoxide. In this paper, the model of blast furnace operation with biomass syngas injection is established by using Aspen Plus software. The simulation results demonstrate that the minimal coke consumption with syngas injection could be 320 $kg \cdot t_{HM}^{-1}$ when an injection rate is about 60 $kg \cdot t_{HM}^{-1}$, while the coke consumption could be reduced to 316.5 $kg \cdot t_{HM}^{-1}$ when 50 $kg \cdot t_{HM}^{-1}$ of hydrogen is injected. With the optimal syngas injection rate, CO_2 emissions of the blast furnace can be reduced by 40.8% when compared with that of typical operation when coke rate is 385 $kg \cdot t_{HM}^{-1}$.

Keywords: blast furnace, biomass, syngas, hydrogen, process simulation

NONMENCLATURE

Abbreviations

AUXM	Auxiliary Material
BF	Blast Furnace
HM	Hot Metal
PC	Pulverized Coal
RA	Reducing Agent

Greek Letters

τ	Replacement ratio, $kg_{coke} \cdot t_{ara}^{-1}$

Subscripts

ara	Auxiliary reducing agent
inj	Injection
mit	Mitigated
ref	Reference

1. INTRODUCTION

Current iron and steel production depends substantially on blast furnace (BF) process which produces about 70% of total world steel production [1]. The goal of this process is to reduce the iron oxides into iron by the use of carbon and hydrogen related reducing agents i.e. coke, coal, oil, natural gas and hot reducing gases, etc. [2]. The carbon in these fossil-based energies is finally released in the form of CO_2 to the environment. BF is the most energy-intensive step in the integrated steelmaking process and generates large quantities of CO_2 [3]. Thus a number of production processes or modifications of existing ones to improve BF efficiency and reduce emissions have been developed [4]. One alternative solution that offers great potential is to use renewable biomass-generated reductants that could replace part of coke in BF.

Thermochemical conversion technologies make it possible to produce solid, liquid and gaseous biomass-based reducing agents. Charcoal from slow pyrolysis could replace pulverized coal (PC) injection in the BF. To obtain the same combustibility of biochar with that of the coal, a longer raceway or smaller particle size is required [5]. Bio-oil from fast pyrolysis of heterotrophic

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microalgae has nearly comparable heating value to fossil-based heavy oil, which has high quality for use in metallurgical purposes [2, 6]. Biomass gasification has been perceived as an promising process for producing syngas and synthetic natural gas which are rich in hydrogen, carbon monoxide and methane [7]. The main requirement of syngas utilisation in ironmaking applications is its sufficient reducibility. Although using syngas from biomass gasification has been investigated in numerous work [8, 9], the process analysis of biomass syngas behavior in BF has rarely been reported.

In this paper, biomass-based syngas is used as the auxiliary reducing agent during the BF process. The savings in the coke consumption and reduction of CO_2 emissions are examined. Also the performance of biomass syngas as an auxiliary reducing agent in BF is compared with that of hydrogen.

2. SYSTEM DESCRIPTION

Fig 1 indicates the general schematic diagram of BF operation with biomass syngas injection. The gasification technologies of biomass can be divided into allothermal, autothermal and entrained flow gasifiers [8]. The entrained flow gasifiers technology is chosen in this work, in which the ratio of hydrogen and carbon monoxide in the syngas is 1. The syngas produced from biomass gasification is required to be cleaned and purified. Afterwards, biomass syngas could be introduced into the BF by injecting through tuyere. Hydrogen will also be used separately for performance comparison.

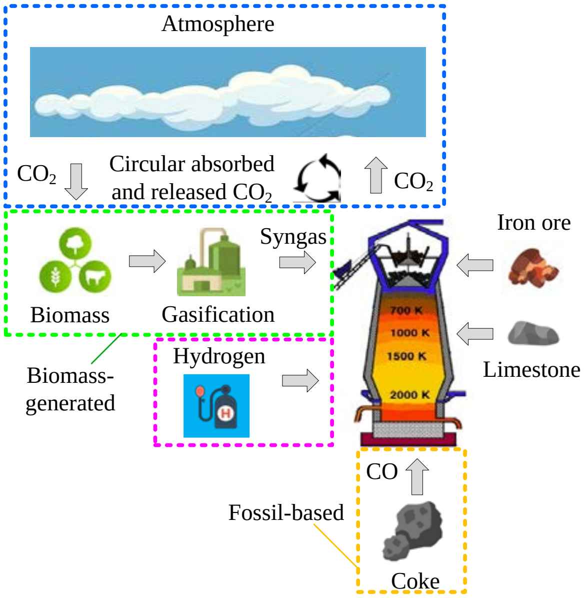

Fig 1 Schematic diagram of BF operation with biomass syngas injection.

3. METHODOLOGY

3.1 Aspen model

The input stream parameters of BF model in Aspen Plus are listed in Table 1. Fig 2 shows the flowsheet of the BF process. Solids method is used to calculate the properties of all the components. All the components operate under steady-state conditions.

Table 1. Input stream parameters of BF model in Aspen Plus.

Parameter	Component
Ore	Fe_2O_3, SiO_2, Al_2O_3, MgO, MnO
Auxiliary material	$CaCO_3$
Coke	C, N, H, O, S
Pulverized coal	C, N, H, O, S
Hot air	N_2, O_2
Oxygen	O_2
Water	H_2O
Syngas	H_2, CO

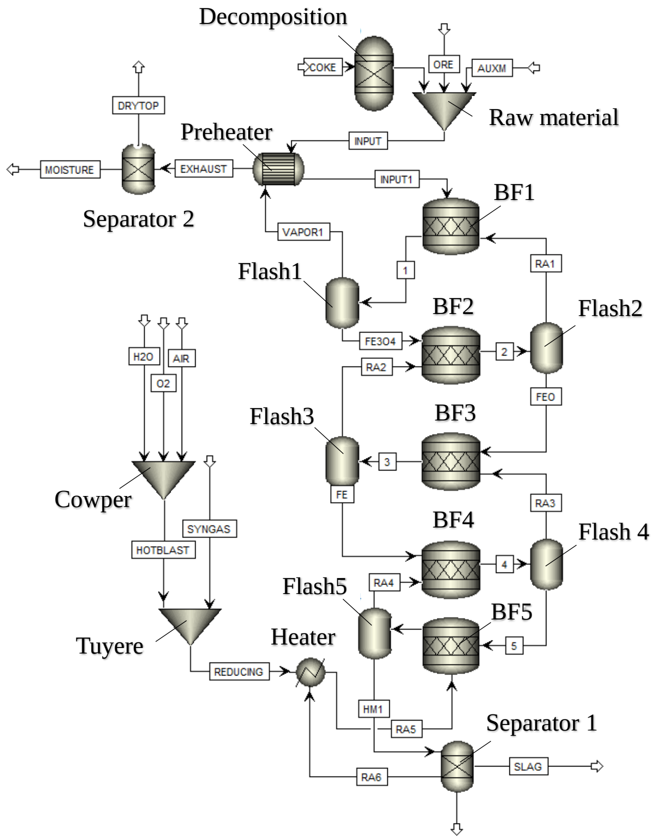

Fig 2 Flowsheet of the BF model in Aspen Plus.

3.2 Performance evaluation

To evaluate the reduction of coke consumption and mitigation of CO_2 emissions when using biomass syngas in the BF process, an exemplified case [10] that considers a common BF operation using coke and PC injection is used for comparison. The process parameters of the reference case are listed in Table 2. Meanwhile, to assess the performance of biomass syngas, pure hydrogen as an auxiliary reducing agent is simulated in the model. Since coke is the main investigated target in BF process, other issues, e.g. iron capacity and quality are not concerned.

Table 2. Process parameters of the reference case [10].

Parameters	Value
Coke consumption	385 kg·t_{HM}^{-1}
PC injection	112 kg·t_{HM}^{-1}
Amount of hot air	1045 Nm^3·t_{HM}^{-1}
Amount of oxygen	100 Nm^3·t_{HM}^{-1}
CO in BF top gas	24.5 kg·t_{HM}^{-1}
CO_2 emissions	1145.4 kg·t_{HM}^{-1}

The replacement ratio τ is used to describe the change of the coke rate resulting from using a certain amount of auxiliary reducing agent [4], which can be expressed as Equation (1):

$$\tau = \frac{\Delta m_{\mathrm{coke}}}{\Delta m_{\mathrm{ara}}} = \frac{m_{\mathrm{ref,coke}} - m_{\mathrm{coke}}}{\Delta m_{\mathrm{ara}}} \quad (1)$$

The specific auxiliary reducing agent demand per mitigation of CO_2 emissions can be evaluated as Equation (2):

$$m_{\mathrm{mit,ara}} = \frac{m_{\mathrm{inj,ara}}}{m_{\mathrm{ref,CO_2}} - m_{\mathrm{CO_2}}} \quad (2)$$

4. RESULTS AND DISCUSSION

Fig 3 shows the change of coke rate when the mass of syngas injected ranges from 0 kg·t_{HM}^{-1} to 60 kg·t_{HM}^{-1}. It can be observed that the coke rate decreases with the increase of injected syngas. The optimal coke rate of 320 kg·t_{HM}^{-1} is achieved at an injection rate of 60 kg·t_{HM}^{-1}. Pure hydrogen as a reducing agent could have a superior ability to replace coke. Also worth noting that a significant reduction of coke is found when the hydrogen is injected from 10 kg·t_{HM}^{-1} to 40 kg·t_{HM}^{-1}, whereas the coke rate tends to be constant after 40 kg·t_{HM}^{-1}. The minimal coke consumption is 316.5 kg·t_{HM}^{-1} when an injection rate of hydrogen is 50 kg·t_{HM}^{-1}. This is mainly because higher injection of hydrogen requires additional oxygen to maintain a proper adiabatic flame temperature. When the hydrogen injection is larger than 40 kg·t_{HM}^{-1}, the oxygen content is not enough in BF, which leads to no extra reducing reaction by hydrogen.

Fig 4 illustrates the influence of different reducing agents on coke rate by using the replacement ratio. It is indicated that more coke could be saved when injection rate of syngas increases from 10 kg·t_{HM}^{-1} to 40 kg·t_{HM}^{-1}, while the replacement ratio varies slightly after 40 kg·t_{HM}^{-1}. This could be attributed to the increased amount of hydrogen with the increment of syngas. When injecting pure hydrogen into BF, less coke can be replaced per injected amount of hydrogen for an injection rate larger than 20 kg·t_{HM}^{-1}. Thus it reveals that low injection rates provide a better result to save the coke.

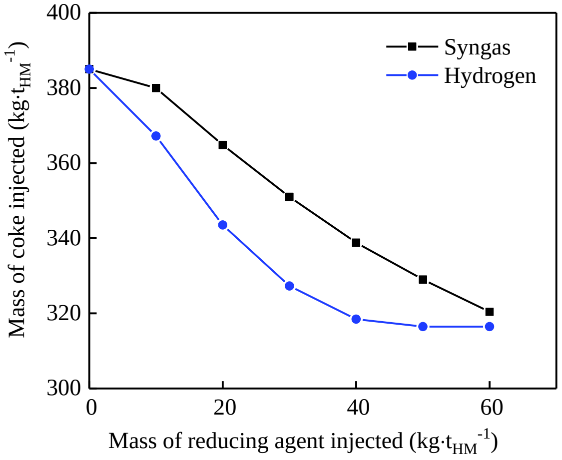

Fig 3 Coke rate when injecting reducing agents at different compositions.

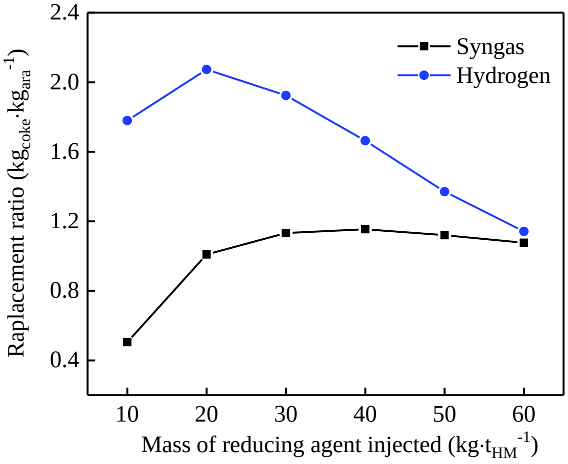

Fig 4 Replacement ratio when injecting reducing agents at different compositions.

Fig 5 shows the resulting CO_2 emissions of on-site BF process in terms of injecting different reducing agents. CO_2 emissions can be continuously decreased from 1076.3 kg·t_{HM}^{-1} to 678.5 kg·t_{HM}^{-1} by increasing the injection rate of syngas. The result can be reduced by 40.8% compared to that of operation from the reference case when the coke rate is 385 kg·t_{HM}^{-1}. The hydrogen in syngas plays a main role on the mitigation of CO_2 emissions. Similar to the trend of coke ratio when pure hydrogen as a reducing agent, on-site CO_2 emissions will change slightly when the feed rate of hydrogen is larger than 40 kg·t_{HM}^{-1}. This could be also because of the low efficient reducing ability of hydrogen at a higher injection rate in BF.

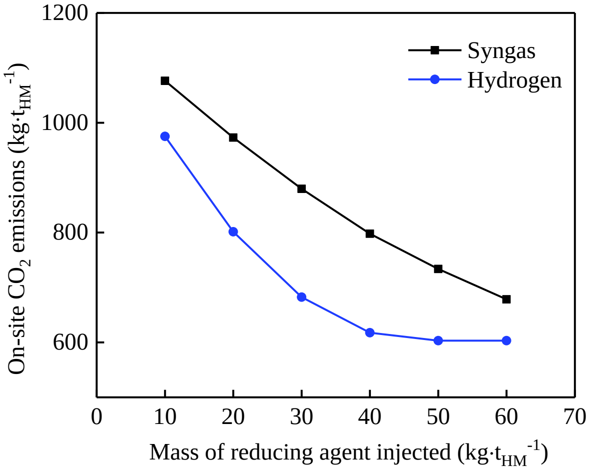

Fig 5 Resulting CO_2 emissions in terms of injecting different reducing agents.

Fig 6 indicates the ability of different reducing agents to reduce CO_2 emissions, which are determined by the specific reducing agent demand per mitigated tonne of CO_2. It can be observed that injection rate of syngas is larger than that of hydrogen to reduce the same amount of CO_2 emissions. However, significant increment of hydrogen demand is observed when the pure hydrogen is injected higher than 20 $kg\cdot t_{HM}^{-1}$. Accordingly, the higher injection of hydrogen results in less efficient mitigation of CO_2 emissions.

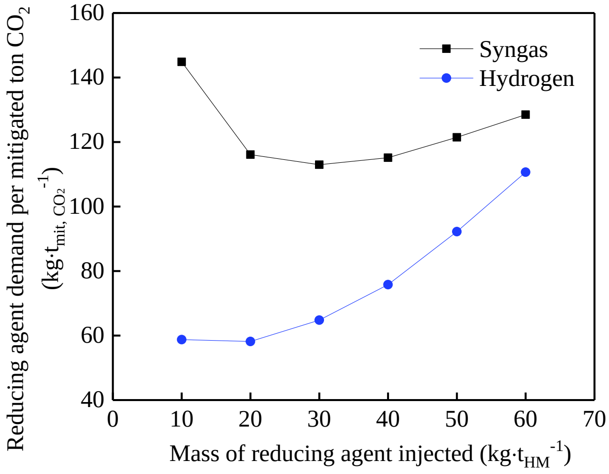

Fig 6 Specific reducing agent demand per mitigated tonne of on-site CO_2 emissions.

5. CONCLUSIONS

This study aims to investigate the performance of injecting biomass syngas as an auxiliary reducing agent into BF. The minimal coke consumption with syngas injection could be 320 $kg\cdot t_{HM}^{-1}$ when an injection rate is 60 $kg\cdot t_{HM}^{-1}$. With the optimal syngas injection rate, CO_2 emissions of BF can be reduced by 40.8% when compared with that of typical operation. Although pure hydrogen has a superior ability to save coke and reduce CO_2 emissions, the higher injection of hydrogen could also result in an unsteady result. A more detailed analysis could be our future work.

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