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CO_2 Gasification of Charcoals in the Context of Metallurgical Application

Hau- Huu Bui[a,*], Liang Wang[b], Khanh- Quang Tran[c], Øyvind Skreiberg[b], Apanee Luengnaruemitchai[a]

[a] The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok 10330, Thailand
[b] SINTEF Energy Research, P.O. Box 4761 Sluppen, NO-7465 Trondheim, Norway
[c] Department of Energy and Process Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

Abstract

The CO_2 gasification reactivity of Norwegian spruce charcoals from stem wood and its forest residue produced at different pressures was investigated in the present study. The gasification behavior was analyzed thermogravimetrically at different gasification temperatures of 800, 850 and 950°C, followed by a kinetic modelling applying the random pore model (RPM) and overlapped grain model (OGM). It is found that gasification temperature has a considerable influence on the reactivity of charcoals. Higher carbonization pressures reduce the gasification reactivity of the produced charcoals towards CO_2. The employed kinetic models represents well the experimental data. The initial porosity computed through the OGM is found to depend on the carbonization pressure. The activation energy is found in the range of 210 to 230 kJ/mol, in line with the values reported in the literature.

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Keywords: Charcoals; Flash Carbonization; Pressures; Gasification Kinetics.

1. Introduction

The iron and steel production is accounting for approx. 70% of total greenhouse gas emission from primary metal production and is also the fourth biggest industry using fossil fuels [1]. About 2.2 ton of CO_2 is released for the production of one ton crude steel on average [2]. An ambitious target was established by steel producers to decrease both direct and indirect CO_2 emission by 50% or even more by 2050 [3]. Hence, for a long-term perspective, the replacement of fossil fuel-based reductants with carbon derived from biomass such as charcoal is necessary to reduce the greenhouse gas footprint from metal production, especially from iron and steel industry, but also from the expanding silicon production industry.

* Corresponding author.
E-mail address: Hau.H.Bui@gmail.com.

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However, it is still challenging to develop and manage woody biomass resources on a sustainable basis and advance economical charcoal production technologies with lower environmental impacts [1]. Indeed, there are several potential applications of charcoal in steelmaking processes including sintering solid fuel, coke making blend component and steelmaking recarburiser [3]. In addition to this, the use of charcoal as reductant also improves the metal quality and offers a possibility of higher productivities [4]. On the other hand, charcoal is also playing an important role in silicon industry in which the silicon losses might reach 20% of the mass of silicon charged to the furnace due to the low reactivity of reductants [5]. In fact, the reactivity of reductants is a primary factor to determine the silica reduction process efficiency. A CO_2 gasification reactivity test is often conducted to select the right reductants due to its simplicity [6].

The present work aims at performing a comparison on the kinetic modelling of CO_2 gasification of charcoals produced via flash carbonization at different pressures. To our best knowledge, no investigations related to this aspect are available from open literature. Additionally, a new approach is proposed to determine the initial porosity of charcoal samples.

2. Materials and Method

The charcoals used in the present study is prepared from Norwegian spruce stem wood and forest residues containing mainly branches and tops (GROT). After cutting into small pieces and drying at 105°C for 24 h, the raw samples was subjected to flash carbonization at about 500°C and different pressures of 7.9 and 21.7 bar [7]. A thermogravimetric analyzer (TGA) "Mettler Toledo TGA/SDTA 851^e" was also used to produce charcoal at atmospheric pressure (1 bar). The proximate analysis of produced charcoals was carried out in accordance with a standard method, ASTM D 1762-84, whereas the elemental analysis was performed by employing a Eurovector EA 3000 CHNS-O Elemental Analyzer. Characteristics of produced charcoals are given in Table 1.

Table 1 Proximate and ultimate analysis of charcoal samples (dry basis, wt%)

Samples	Charcoal production pressure, bar	Proximate analysis			Ultimate analysis				
		VM	Ash	FC	C	H	N	S	O
Spruce	7.9	18.1	1.7	80.2	77.35	3.68	0.29	<0.02	18.66
	21.7	18.8	1.1	80.1	76.36	3.5	0.47	<0.02	19.55
Spruce GROT	7.9	13.1	6.1	80.7	83.49	2.65	0.56	<0.02	13.28
	21.7	28.5	3.7	67.7	77.34	3.79	0.66	<0.02	18.19

VM: Volatile matter; FC: Fixed carbon

The gasification behaviour of charcoals towards CO_2 was investigated by using the above-mentioned TGA. Approximately 2 mg of samples was used for every experimental run. The sample was heated from room temperature to different gasification temperatures of 800, 850 and 950°C with a heating rate of 13°C/min under a nitrogen flow of 100 ml/min. After reaching the gasification temperature, the nitrogen flow was replaced by a CO_2 flow with the same flow rate. The charcoal gasification was maintained until a constant weight was reached. In the present study, two kinetic models, the random pore model (RPM) and overlapped grain model (OGM), were employed for kinetic modelling and simulation. The RPM takes into account the overlapping of pore surfaces and the change of surface area available for reaction along with the progress of the reaction [8]. The reaction rate under kinetic control is mathematically described by Eq. 1 [9]

$$\frac{d\alpha}{dt} = k\,(1-\alpha)\sqrt{[1-\psi\ln(1-\alpha)]} \quad (1)$$