

Counter-flow air gasification of woody biomass pellets in the auto-thermal packed bed reactor



Joseph H. Kihedu^{a,*}, Ryo Yoshiie^a, Yoko Nunome^b, Yasuaki Ueki^b, Ichiro Naruse^b

^a Graduate School of Engineering, Nagoya University, Furocho, Chikusa-ku, Nagoya 464-8603, Japan

^b EcoTopia Science Institute, Nagoya University, Furocho, Chikusa-ku, Nagoya 464-8603, Japan

HIGHLIGHTS

- Air was simultaneously fed from the top and from the bottom of the reactor.
- With downdraft air at 12 L/min and 4 L/min updraft air, LHV was 4.28 MJ/m³ N.
- Tar reduction compromised with the syngas LHV improvement.
- Increasing the updraft air, improved carbon conversion but affected the efficiency.
- At optimum conditions, cold gas efficiency was 77% and carbon conversion was 88%.

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ABSTRACT

Counter-flow packed bed gasification was carried out featuring a combination of downdraft and updraft operation modes. A column reactor of inside diameter 102 mm and 1000 mm height was used. Downdraft and updraft air supply were varied while the total air supply was maintained constant. Counter-flow gasification with downdraft air supply at 12 L/min and updraft air at 4 L/min offered optimal conditions, producing syngas with 4.28 MJ/m³ N LHV and 5.84 g/m³ N tar content. Under similar operating conditions, cold gas efficiency was about 77% while carbon conversion reached 88%. Increasing the updraft air flow resulted in reduced tar generation and increased carbon conversion, however, the syngas LHV and cold gas efficiency were affected adversely.

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1. Introduction

Downdraft and updraft operation modes for biomass gasification in the packed bed reactor have extensively been reported [1–3]. These modes are named from the directions of gas flow inside the upright standing gasifier reactor that is either downwards or upwards, respectively. Under both of the operation modes, if the solid fuel is fed from the top of the reactor, then reaction zones in a top to bottom arrangement are; drying, pyrolytic reactions and char reduction zone [1,2]. In addition to these reaction zones, during auto-thermal gasification process, combustion zone would occur either at the top or at the bottom of the packed bed during downdraft or updraft gasification, respectively.

* Corresponding author. Address: Department of Mechanical and Industrial Engineering, University of Dar es Salaam, Tanzania. Tel.: +255 22 2410754; fax: +255 22 2410114.

E-mail addresses: kihedu@udsm.ac.tz (J.H. Kihedu), ryoshiie@mech.nagoya-u.ac.jp (R. Yoshiie), nunome.yoko@mech.nagoya-u.ac.jp (Y. Nunome), ueki@mech.nagoya-u.ac.jp (Y. Ueki), naruse@mech.nagoya-u.ac.jp (I. Naruse).

In order to understand the packed bed gasification process, various researchers have embarked on investigating various parameters. Our previous work [1] reported on downdraft and updraft gasification characteristics of biomass pellets in the packed bed reactor. Pérez et al. [3] studied the effect of operating and design parameters while Simone et al. [4] assessed the feasibility and reliability of biomass pellet gasification in a downdraft gasifier. Tinaut et al. [5] developed model for studying the effect of biomass particle size and air superficial velocity on the gasification process in a downdraft gasifier. It can be noted that many researchers preferred downdraft gasification rather than updraft gasification. This is due to relatively lower tar generation during downdraft gasification under which further tar cracking occurs as product gases pass through the high temperature reduction zone packed with charred biomass [1,6]. As opposed to that, pre-mature release of product gases under updraft gasification results into high tar content of the syngas. However, updraft gasification produces syngas with favorably slightly higher LHV compared to downdraft gasification.

Higher LHV and lower tar generation remain to be the principal objective for biomass gasification studies. Biomass gasification by

using air is reported to produce syngas with LHV around 4 MJ/m³ N and tar content of about 20 g/m³ N [1,3,7] while the basic requirements for gas application in the engine are LHV of above 3.5 MJ/m³ N and tar concentration of less than 0.02 g/m³ N [8,9]. Although syngas LHV from these results indicate promising results, tar generation is still far above the required values. Primary methods for tar removal from the syngas include improvement of operating parameters, the use of catalysts and system design modifications [6,8,9]. Secondary methods include thermal or catalytic tar cracking and cleaning. Brandt et al. [6] reported on remarkable tar reduction after oxidation of pyrolysis gas and passage of the producer gas through the char bed. Cao et al. [9] re-circled part of the syngas into the reactor and introduced secondary air to produce syngas with extremely low tar content. Wang et al. [8] used a steam tar reformer and concluded a trade-off relation between improvement of syngas LHV and reduction of tar generation.

In this paper, counter-flow gasification of woody biomass pellets in an auto-thermal packed bed reactor is reported. Counter-flow features a combination of downdraft and updraft targeting at improvement of gas LHV while reducing tar generation. Downdraft and updraft air supply were varied to find the optimal operating conditions. Analyses performed include syngas composition, tar generation as well as temperature profiles and gas concentration in the reactor. In addition to that, syngas LHV, cold gas efficiency and carbon conversion are also presented.

2. Experimental section

2.1. Samples used

Pellets made from whole body black pine (*pinus thunbergiana*) were used in this study. These pellets were about 8.5 mm long and, 6.5 mm in diameter with apparent density of 1.1 g/cm³. Proximate and ultimate analysis results for these pellets are presented in Table 1. Prior to the experiment, pellets were dried at 107 °C for 24 h.

2.2. Gasification facility

Gasification reactor used in this study was made of 1000 mm long reactor SUS304 stainless steel tube having 114 mm outside diameter and 6 mm wall thickness. Gas sampling ports were located at 50 mm, 100 mm, 200 mm, 300 mm, 400 mm, 500 mm, 600 mm, 700 mm, 800 mm, 900 mm and 950 mm from the bottom of the reactor as illustrated in Fig. 1a. Moreover, 11 temperature thermocouples were also located at similar heights with gas sampling ports. These thermocouples were connected to the data logger and hence computer for data retrieval. The biomass hopper at the top of the reactor was packed with pine pellets and purged with N_2 at 1.6 L/min to avoid pre-combustion as shown in Fig. 1b. The screw feeding mechanism supplied biomass pellets into the reactor, where the pellets were supported by stainless wire mesh located at the bottom of the reactor. The height of biomass packed bed was checked by using a metering rod inserted from the top of the reactor. Ash from the spent biomass passed through the stainless wire mesh and dropped into the ash tray.

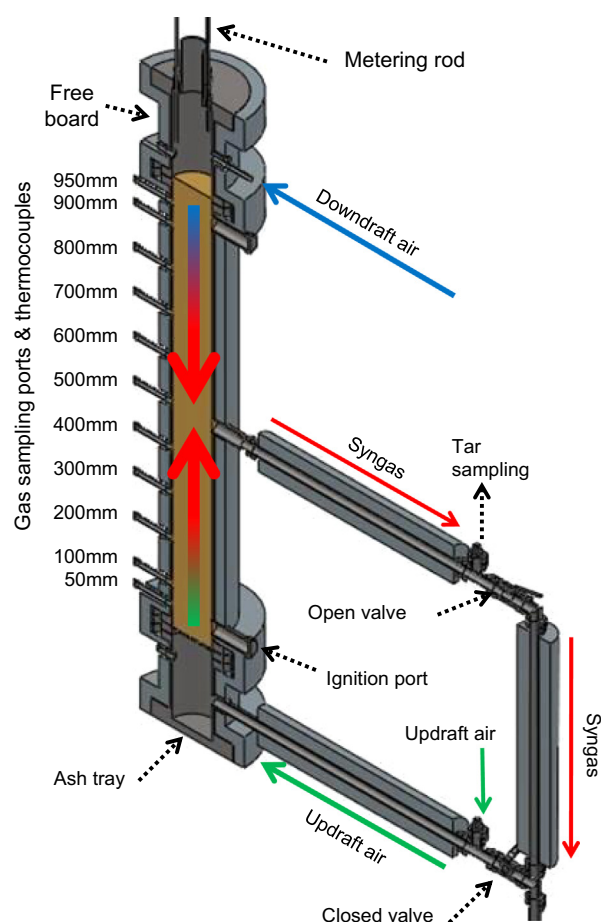


Fig. 1a. Counter-flow assembly for the packed bed reactor.

by gravity. The two exits for the syngas from the reactor were located at the middle and at the bottom of the reactor. From either of the two exits, syngas was then passed through the water-cooled cooling tower made of two concentric tubes. Part of the syngas was sampled for analysis of gaseous composition by using a microgas chromatograph, Agilent 3000 A.

2.3. Gasification procedures

During the *start-up* period, the reactor was fed with about 0.5 kg of biomass pellets forming about 90 mm bed height as presented in Table 2. This amount of biomass was ignited by using a propane burner through the ignition port (Fig. 1a). During this period, the downdraft air was supplied at 20 L/min while the bottom syngas exit was opened and the middle exit closed. When the temperature of about 250–300 °C was attained, feeding of biomass pellets at 20 g/min was started. Bed heights were checked in every 20 min intervals and allowed to rise to 1000 mm. In order to maintain the packed bed height during the *continuous operation modes* of the reactor, biomass supply was reduced to 9 g/min and air supply was reduced to 16 L/min (Table 2). After attaining steady state, i.e.

Table 1
Proximate and ultimate analysis of the whole black pine pellets.

Proximate analysis				Ultimate analysis				
As received (wt.%)		Dry basis (wt.%)		Dry ash free basis (wt.%)				Balance (wt.%)
Moisture	VM	FC	Ash	C	H	N	S	O
4.64	83.58	15.81	0.61	49.25	6.65	0.91	–	43.19

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