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An advanced biomass gasification technology with integrated catalytic hot gas cleaning
Part I. Technology and initial experimental results in a lab-scale facility

Li Dong, Mohammad Asadullah [1], Shu Zhang, Xiao-Shan Wang, Hongwei Wu, Chun-Zhu Li *

Fuels and Energy Technology Institute, Curtin University of Technology, GPO Box U1987, Perth, WA 6845, Australia

HIGHLIGHTS

▶ A new biomass gasification technology with compact design, integrated tar reduction and minimised oxygen consumption.
▶ Adverse effects of volatile–char interactions are minimised.
▶ Key features demonstrated with a lab-scale pilot plant.

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ABSTRACT

High tar contents and low carbon conversion levels are two major problems in traditional biomass gasification technologies. Based on our research results especially on the volatile–char interaction and catalytic tar reforming, an advanced biomass gasification technology integrated with catalytic hot gas cleaning has been developed to produce high quality clean fuel gas. A lab-scale pilot gasifier was constructed and employed to demonstrate this technology. The experimental results show that the technology could efficiently gasify biomass into a high-quality fuel gas at atmospheric pressure and temperatures below 1000 °C. The tar content in the gasification product gas could be reduced to well below 100 mg Nm^{-3} by using char-based hot gas cleaning catalysts.

1. Introduction

The syngas produced from coal/biomass gasification can be used to generate electricity in a gas turbine and synthesise hydrocarbon fuels and other high-value chemicals. Gasification is one of most promising routes to cope with the variability of fuel quality for energy supply as well as to decrease pollutant emissions. Power generation based on biomass gasification would generally feature high reactivity and, more importantly, low net greenhouse gas emissions.

However, biomasses tend to give high volatile yields (80 wt% or more on the dry basis). The incomplete reforming of these volatiles will result in high concentrations of tarry materials in the gasification product gas, limiting the use of the product gas. The popular and commercial method to remove tarry materials from product gas is scrubbing with a liquid such as water, which not only is a complicated unit operation but would produce a wastewater stream that must be further treated [1–4]. Therefore, the removal of tarry materials from the gasification product gas is normally a very costly operation, amounting to a significant fraction of the overall gasification capital and operating costs [5]. Reducing the cost of gas cleaning, especially the removal of tar, is a major means to reduce the overall cost of biomass gasification.

The reactions of char and volatiles produced during biomass gasification are two core factors to control the whole gasification process. The interactions between the char and the volatiles can impact on every aspect of biomass gasification, including the char structural characteristics [6–10] and the volatilisation of their inherent alkali and alkaline earth metallic (AAEM) species [10–12]. Enhanced interactions between volatiles and char would make char more stable [13–15] and enhance the volatilisation of AAEM species [16–19], leading to the deactivation and slow gasification of char. In order to achieve higher char conversion, a larger gasifier would be required, which would in turn increase the construction and operation costs. Minimising the adverse impacts of volatile–char interactions to improve the char reactivity should become a

* Corresponding author. Fax: +61 8 9266 1138.
E-mail address: chun-zhu.li@curtin.edu.au (C.-Z. Li).
[1] Present address: Faculty of Chemical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

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major consideration in the development of new biomass gasification technologies.

In a practical gasifier, oxygen must be supplied into the gasifier to generate the heat required for the operation of the gasifier, especially the heat demand of endothermic gasification/reforming reactions. In many biomass gasification technologies being developed, the supply and consumption of O_2 (air) is a major issue [20]. Oxygen is frequently consumed mainly by the reactive volatiles, leaving the less reactive char to be gasified with H_2O and CO_2. The gasification of char becomes the rate-limiting step. Much more oxygen (air) than the theoretical oxygen demand has to be supplied to achieve a reasonable level of char gasification (and volatile reforming), resulting in low efficiency. The heating value of the gasification product gas is also low because it contains excessive amounts of combustion products (CO_2 and H_2O) and it is diluted by N_2 as part of the air fed into the gasifier. Therefore, minimising the air (O_2) consumption should be another key consideration of new gasification technology development.

The abilities to minimise the adverse effects of volatile–char interactions, to remove/convert tar cheaply without the need to clean up a waste steam and to minimise air (oxygen) consumption become key criteria to develop advanced gasification technologies.

There have been a number of commercial gasification technologies such as those developed by Shell and Lurgi [21]. These technologies, while successful for large-scale coal gasification, have not been specially developed for the small-scale gasification of distributed biomass. The costs to centralise distributed biomass for gasification using these large-scale gasifiers can be prohibitively high, making it a commercially infeasible way of biomass utilisation. Furthermore, many of these large-scale gasification technologies have been originally developed for coal gasification (not necessarily considering the special features of biomass) and normally operate at high pressure and high temperature. These operating conditions are not optimised for biomass gasification. Therefore, there has been a need for small-scale gasification technologies using distributed biomass, which has spurred international efforts to develop such new technologies.

In addressing the key criteria in biomass gasification technologies as mentioned above, we developed an advanced biomass gasification technology [22]. The volatiles–char interactions are minimised to promote rapid char conversion and optimise/minimise the consumption of O_2. Char-supported catalysts are used to clean the tarry product gas without the expensive liquid-scrubbing operation. In this part, we present the key features of our novel gasification technology. The brief feasibility of some features of this technology has been demonstrated through experiments in a lab-scale gasification pilot plant facility.

2. An advanced gasification technology with catalytic hot gas cleaning

Fig. 1 presents the conceptual illustration of our advanced gasification technology. Differing from other gasification technologies where the pyrolysis of biomass and char gasification are intimately coupled in the same zone, there are four reaction zones in the gasifier: the drying and pyrolysis of biomass (Zone 1), the gasification of char (Zone 2), the reforming of volatiles (Zone 3) and the hot gas cleaning with a solid catalyst (Zone 4).

As is shown in Fig. 1, once the biomass particles enter the reactor, they will be heated up through their contact with the upcoming hot gas stream. The pyrolysis of biomass would generate volatiles (including pyrolytic water) and char in Zone 1. The solid char particles formed from the pyrolysis of biomass particles will descend by gravity inside the gasifier and will meet with the incoming O_2 to be gasified by the incoming O_2 to form CO and

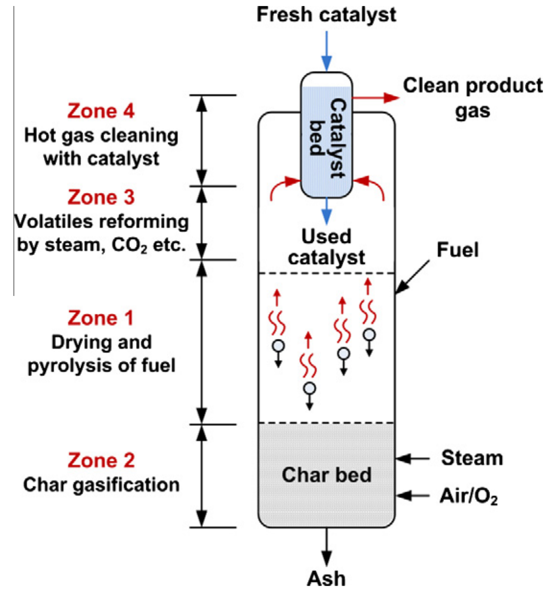

Fig. 1. The conceptual illustration of the advanced gasification technology with integrated catalytic hot gas cleaning.

CO_2 in the absence of volatiles (also called partial combustion) (in Zone 2). The hot gas from the char–O_2 reactions (whose temperature is regulated by the addition of steam) will travel up inside the reactor to supply the heat required by the pyrolysis and the volatile reforming reactions. The volatiles will mix with the upcoming hot gas stream and flow upwards, during which the reforming of volatiles with steam (and CO_2 as well as the residual O_2, if any) will take place in Zone 3. The product gases from the reforming of volatiles and the gasification of char, containing tar and other impurities such as NH_3, HCN and vaporised inorganic species will enter a char-supported catalyst moving bed (Zone 4). The spent catalyst will drop into the bottom of gasifier to be gasified.

By considering the structural features and gasification behaviour of biomass, this advanced gasification technology has the following unique features. It should be noted that some of these features stated below are based on the conceptual analysis of our technology and that their experimental validation will be the topics of our future studies.

(1) *Compact design*: Biomass gasification and the hot gas cleaning can take place in one integrated reactor, unlike other competing technologies that need to have more than one reactor to achieve complete gasification. This compact design would make it feasible to operate this gasifier for the small scale (a few MWe or less) distributed electricity generation applications in remote areas.
(2) *Production of clean combustible gas*: This gasification technology can use char or char-supported catalysts [22] to clean the gasification product gas to reduce its tar concentration to below 100 mg m^{-3} (100 mg m^{-3} being a commonly accepted standard tar concentration in product gas in order for the gasification product gas to be burned in a gas engine/turbine to generate electricity [23,24]). By now, most existing technologies rely on the scrubbing (washing) of the raw gasification product gas with a liquid (e.g. water or biodiesel) to remove tar, which will create a waste liquid stream (e.g. waste water) requiring expensive treatment before the liquid stream can be discharged safely to the environment.