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Review

New concepts in biomass gasification

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ABSTRACT

Gasification is considered as a key technology for the use of biomass. In order to promote this technology in the future, advanced, cost-effective, and highly efficient gasification processes and systems are required. This paper provides a detailed review on new concepts in biomass gasification.

Concepts for process integration and combination aim to enable higher process efficiencies, better gas quality and purity, and lower investment costs. The recently developed UNIQUE gasifier which integrates gasification, gas cleaning and conditioning in one reactor unit is an example for a promising process integration. Other interesting concepts combine pyrolysis and gasification or gasification and combustion in single controlled stages. An approach to improve the economic viability and sustainability of the utilization of biomass via gasification is the combined production of more than one product. Polygeneration strategies for the production of multiple energy products from biomass gasification syngas offer high efficiency and flexibility.

Contents

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1. Introduction

Global warming and climate change concerns result in efforts to reduce CO_2 greenhouse gas emissions by increasing the use of renewable energies and increasing the energy efficiency. Besides solar and wind energy, biomass is considered as a main renewable energy source. In the renewable energy mixture of solar, wind and biomass energy, biomass can be used as adjustable, controlled energy which will be supplied in increased amount when wind and solar energy supply is low.

Since the discovery of the mankind how to make fire, biomass has been the main energy source for thousands of years and still today it contributes in the range of more than 10% to the world energy supply and ranks as the fourth source of energy in the world [1]. In rural agricultural areas, biomass is still the main energy resource for heating and cooking and often it is the only available energy source there. In developing countries in Asia and Africa more than one-third of the total energy consumption is based on biomass. A big advantage of biomass is that it is available at every place all over the world which is in contrast to coal or natural gas. For example, in India which has very large coal reserves of more than 250 billion tons, the coal deposits are just located in the state of Bihar and northeast. Transportation costs play a major role in the distribution of the coal. Biomass in contrast is uniformly and widely distributed over the country [2].

Gasification is a key technology for the use of biomass. It offers a high flexibility in using different kind of feedstock materials as well as in the generation of different products. In principal, all different types of biomass can be converted by gasification into syngas mainly comprising hydrogen, carbon monoxide, carbon dioxide and methane. From this syngas, all kinds of energy or energy carriers – heat, power, biofuels, hydrogen, biomethane – as well as chemicals can be provided. Synthesis of Fischer–Tropsch (FT) diesel, dimethyl ether (DME), methanol and methane are established technical processes. The use of the available biomass resources needs to be highly efficient and sustainable. Gasification offers a high potential and a high process efficiency for the use of biomass [3]. Gasification of biomass is performed by partial oxidation of the carbon contained in the biomass at high temperature using a controlled amount of an oxidant which can be air, pure oxygen or steam. The composition and properties of the syngas depend on the biomass feedstock, the gasifier type and the operation conditions of the gasifier, such as the used oxidant, the temperature and the residence time in the gasifier. Gasification with air leads to a syngas with a heating value of 4–7 MJ/m^3 whereas using pure oxygen or steam as an oxidant leads to significantly higher heating values of the gas of 10–18 MJ/m^3 [4,5].

Biomass comprises a broad range of different kinds of bio materials, such as wood, forest and agricultural residues, waste from wood and food industry, algae, energy grasses, straw, bagasse, sewage sludge etc. The use of different kinds of biomass results in different challenges and solutions for transportation, storage and feeding of the biomass, for operation of the gasifier and for cleaning of the produced syngas. Most commonly used types of biomass gasifiers are fixed bed and moving bed, fluidized bed and entrained flow gasifiers. Fluidized bed and entrained flow gasifiers provide an intensive contact between the gas and the solid biomass which results in high reaction rates and conversion efficiencies. Fixed bed gasifiers typically have a lower heat and mass transfer and often generate higher amounts of tar and char. However, operation and design of fixed bed gasifiers are simpler and they are preferably used in small size. Performance data of the mentioned gasifier types are given in Table 1.

Depending on the use of the syngas, its cleaning needs to be very efficient. Catalytic synthesis reactions or the use in fuel cells for examples require high purity of the syngas. Main impurities in the syngas are fly ash particles and tar. Other impurities in the syngas are typically sulphur compounds (e.g. H_2S, COS), hydrogen chloride, alkalines, and ammonia. Tar formation is a main problem in biomass gasification. Tar condensation at lower temperatures can cause clogging or blockage of pipes, filters, catalyst units or engines. Tar formation also lowers the syngas yield and the heating value of the gas. Tar removal has been the subject of many researches leading to the development of primary and secondary measures for tar reduction. Overviews on this topic are recently given e.g. by Han and Kim [13], by Aravind and de Jong [14] and by Shen and Yoshikawa [15].

In order to promote the utilization of biomass gasification, advanced concepts are required which have to maximize the syngas yield, optimize the gas quality, increase the gas purity, increase the overall process efficiency and improve the economic viability by decreasing system and production costs.

This paper aims to provide a detailed review on such new concepts in biomass gasification. Process integration and combination, polygeneration strategies as well as new gasification concepts are presented as follows (see also Table 2):

- An interesting example for process integration is the recently developed UNIQUE gasifier concept which integrates gasification, gas cleaning and conditioning in one reactor unit. This

Table 1
Performance data of most commonly used gasifier types.

Gasification technology	Gasification temperature/°C	Cold gas efficiency/%	Char conversion/%	Tar content in raw producer gas/g/m^3_N	References
Fluidized bed (FB) gasifier	800–900	<70	<70	10–40	[6]
Circulating fluidized bed (CFB) gasifier	750–850	50–70	70–95	5–12	[7,8]
Fixed bed downdraft gasifier	Max. bed temp.: 900–1050 gas exit temp.: 700	30–60	<85	0.015–0.5	[9,10]
Fixed bed updraft gasifier	Max. bed temp.: 950–1150 gas exit temp.: 150–400	20–60	40–85	30–150	[9,11,12]