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Review

Reduction of tar generated during biomass gasification: A review

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ABSTRACT

One of the main problems that happen during biomass gasification is tar formation, which could make this technology unsuccessfully from a commercial point of view. Tar content present in syngas defines its application, considering that limits - according to desired application - can be very demanding. There are two ways to overcome this problem: by optimizing gasification operation conditions and removal of tar from gas through in-situ (primary methods) or post-gasification (secondary methods) treatments. This way, multiple technologies have been developed considering the balance between efficiency and economy of the process, besides being (ecofriendly) environmentally acceptable. Some aspects related to tar formation, laboratory and industrial methods and technologies for its reduction-removal, as well as research and development in this area are reviewed and evaluated in this paper.

1. Introduction

At a time when mankind is facing to become a victim of its genius, and is not being able to get rid of its own residues, biomass is becoming an ideal option to supply renewable and sustainable resources. Compared with fossil fuels, biomass has not a net CO_2 emission because it consumes atmospheric CO_2 during its growth through photosynthesis, and therefore, emissions generated during its thermal conversion can be considered neutral [1,2]. Thus, it is observed that growing interest in fossil fuel substitution and reduction of greenhouse gases in recent decades, has promoted development a great number of research works about biomass use in energy conversion processes, of which gasification is a remarkable one [3,4].

One of the main problems in biomass gasification, whether it is used for energy purposes or to produce a synthesis gas (syngas), is the issue of dealing with removal of tar formed during pyrolysis stage [5]. Product gas typically leaves the gasifier along with a mist constituted by different tars components released in the form of aerosol, which can condense and form sticky deposits by quenching downstream when they contact cold points of the gasification system. These deposits can further evolve in other more complex molecular arrangements of tar by polymerization, increasing the difficulty for its treatment.

In general, several options are available for tar reduction, which can be divided into two groups: (1) tar reduction in situ, which avoids (depletes) tar formation and (2) post-gasification reduction, which removes tar from the product gas. In-situ reduction is achieved through an adequate control of process operation and use of additives/catalysts during operation, thus tar generation inside gasifier is decreased (limited); when this process is performed in gasifier, quality of product gas increases. Post-gasification reduction, on the other hand, does not interfere with process in the reactor; tar can be removed through physical processes using cyclones, cooling towers/wash columns, electrostatic precipitators among others, or can be chemically treated by thermal and catalytic processes, and partial oxidation. Sometimes it may not be possible to remove tar with the desired efficiency and maintaining the quality of product gas unchanged; in such cases, a combination of in-situ and post-gasification reduction is more effective [6–9]. In this regard, this work presents a review on the different methods used for product gas cleaning obtained from biomass gasification and a broad picture of the state-of-the-art of it.

This paper provides a comprehensive overview of definition, chemical composition and different but complementary tar classification systems, as well as some of the possible mechanism and pathways of both tar formation and tar destruction by thermal cracking and

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catalytic cracking, which has been proposed in literature. Likewise, different methods for destruction and tar removal have been discussed, including some primary tar reduction methods based on operational conditions and gasifier design. In addition, this paper reviews the main tar removal systems used in biomass gasification industrial plants around the world.

2. Gasification of biomass

Gasification is the process of thermochemical conversion of a solid fuel into a mixture of combustible gases, through partial oxidation and high temperatures typically in the range of 800–1,000 °C, mainly when air/oxygen is used as gasification agent [10]; nevertheless, biomass gasification can be carried out in presence of steam taking place endothermic reactions (steam gasification) which encourage a producer gas with high H_2/CO ratio as well as remarkable heating value, but with high energy requirements that must be supplied by external source, which is a drawback. For this reason, a steam/oxygen mixture is recommended for biomass gasification in order to ensure autothermal process.

Thermochemical conversion of carbonaceous material contained in biomass, generating a mixture of non-condensable gases such as carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and hydrogen (H_2), volatile organic compounds (VOCs), tar, water vapor, H_2S, as well as solid residues, char (solid waste with high carbon content) and traces of HCN, NH_3 and HCl. Specific fractions of different species obtained depend on the gasifier type (fixed bed and fluidized bed), process conditions and gasification agents used during gasification process (air, steam, oxygen and/or mixtures between them).

Biomass gasification involves a great number of complex and closely interconnected thermochemical processes. Fig. 1 shows the stages typically found in gasification process whit air as gasification agent in a downdraft gasifier, this scheme begins with biomass drying through its heating until reaching 150 °C, where humidity is converted into steam. Later, thermal decomposition of dry biomass takes place in absence of oxygen or air and their volatile material is vaporized as temperature increases, generating a gas mixture composed mainly of H_2, CO, CO_2, CH_4, gaseous hydrocarbons and steam; as a result of these gases release, biomass is reduced to char, while gaseous hydrocarbons condense at low temperatures to generate liquid tars. Oxygen from air reacts with present combustible substances (pyrolysis gases, produced tars and char) totally or partially oxidizing them, forming CO_2 and steam. Hydrogen present in biomass is also oxidized generating water. As a consequence of oxidation reactions (exothermic reactions) process temperature increases and reduction reactions (endothermic reactions) are favored, allowing char gasification and obtaining a gas rich in H_2, CO, CH_4, which leaves from the bottom of reactor [11].

On the other hand, when gasification process is carried out in a fixed bed updraft gasifier, biomass is fed from the top and gasification agents could be supplied from the reactor side. Gases produced leave from the gasifier top, consequently the reaction regions are different compared with downdraft gasifier as previously described, where thermal energy required for biomass drying is supplied by the total and partial combustion reaction as shown in Fig. 1, while in an updraft gasifier a part of pyrolysis gases are burnt in order to provide the thermal energy needed for drying process.

Both updraft and downdraft gasifier reach high gasification temperatures (1,200–1,400 °C) and significant hot efficiencies (85–95%), nevertheless the mass and heat transfer along of reactor is very poor, which makes it difficult to achieve uniform distribution of temperature and gas composition in the gasifier cross section, so, undesirable hot spots are formed. When fluidized bed reactor (bubbling or circulating) is used for biomass gasification process, the mass and heat transfer is improved due to suitable mixing between biomass and bed material particles, therefore a homogeneous temperature distribution on both axial and radial direction in the gasifier are expected, giving a higher gas yield and higher carbon conversion than a fixed bed gasifier. However, performance of gasification process in fluidized bed system is limited by ash melting temperature; therefore, if gasification temperature increases, a particle agglomeration could be generated, and a bed collapse could occur, so, the use of additives (CaO, MgO) to control the alkaline species responsible to bed agglomeration and a gasification temperature lower than ash melting temperature in fluidized bed gasifier are recommended.

The potential mechanisms of biomass gasification and tar reforming could be expressed by the partial combustion reactions, heterogeneous reactions and homogeneous reactions shown as reactions (1–16) in Table 1. Catalytic reforming reactions cleave the C–C bonds of the

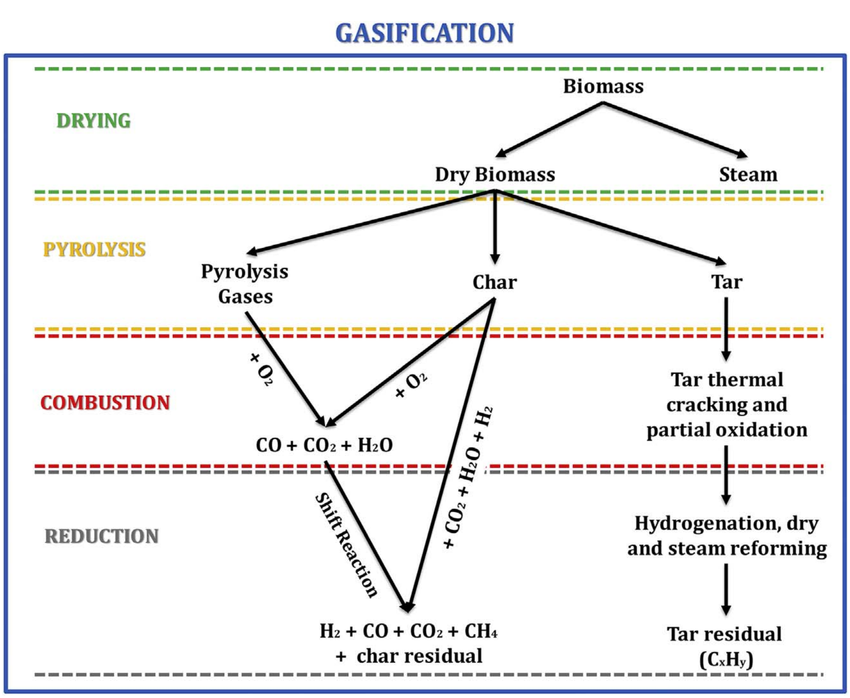

Fig. 1. Stages typically found in biomass gasification in a downdraft gasifier with air.